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Agent-based simulation to support the effectiveness, procurement, and employment of non-lethal weapon systems

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THESIS

AGENT-BASED SIMULATION TO SUPPORT THE EFFECTIVENESS, PROCUREMENT, AND EMPLOYMENT OF NON-LETHAL WEAPON SYSTEMS

by

Samuel P. Gray

June 2017

Thesis Advisor: Thomas W. Lucas
Second Reader: Samuel Huddleston

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The September 11, 2012, attack in Benghazi, Libya, spurred the Marine Corps to establish Special Purpose Marine Air Ground Task Forces (SPMAGTF) Crisis Response elements to support combatant commanders. Two key tasks for these SPMAGTFs are to be able to conduct an embassy reinforcement and employ Non-Lethal Weapons (NLW).

Using agent-based simulation and design of experiments, this thesis explores the effectiveness of NLW within a dismounted patrol conducting a simulated mission in support of an embassy reinforcement. The XM1116 Extended Range Marking Munition is a blunt-force munition designed to incapacitate noncompliant individuals. The simulated mission is set in the city of Abuja, Nigeria, which during the mission would be considered a semi-permissive environment. The goal of the research is to answer three key questions from the Joint Non-Lethal Weapons Directorate: How many NLWs should a Marine infantry platoon carry while conducting a dismounted patrol? Where should those NLWs be located within the patrol? What is the best maximum effective range to have on a blunt-force munition to reduce the number of times a mission utilizes lethal munitions? After conducting analysis on the data obtained from over 9,600 simulated embassy reinforcement missions, it is evident that: (1) 14 NLWs within the patrol provide the greatest reduction in lethal shots fired while still making tactical sense; (2) each fire team within the patrol should have one NLW along with the squad leaders, platoon commander, and platoon sergeant; and (3) the ideal maximum effective range for the NLW is 75 meters.

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AGENT-BASED SIMULATION TO SUPPORT THE EFFECTIVENESS, PROCUREMENT, AND EMPLOYMENT OF NON-LETHAL WEAPON SYSTEMS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

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Using agent-based simulation and design of experiments, this thesis explores the effectiveness of NLW within a dismounted patrol conducting a simulated mission in support of an embassy reinforcement. The XM1116 Extended Range Marking Munition is a blunt-force munition designed to incapacitate noncompliant individuals. The simulated mission is set in the city of Abuja, Nigeria, which during the mission would be considered a semi-permissive environment. The goal of the research is to answer three key questions from the Joint Non-Lethal Weapons Directorate: How many NLWs should a Marine infantry platoon carry while conducting a dismounted patrol? Where should those NLWs be located within the patrol? What is the best maximum effective range to have on a blunt-force munition to reduce the number of times a mission utilizes lethal munitions? After conducting analysis on the data obtained from over 9,600 simulated embassy reinforcement missions, it is evident that: (1) 14 NLWs within the patrol provide the greatest reduction in lethal shots fired while still making tactical sense; (2) each fire team within the patrol should have one NLW along with the squad leaders, platoon commander, and platoon sergeant; and (3) the ideal maximum effective range for the NLW is 75 meters.

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THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made within the time available to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	Agent-Based Simulation
AQ	Al Qaeda
CMC	Commandant of the Marine Corps
DES	Discrete-Event Simulation
DOD	Department of Defense
DOE	Design of Experiments
DOS	Department of State
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy
DMSO	Defense Modeling and Simulation Office
ERMM	Extended Range Marking Munition
FB	Front-Back
FTL	Fire Team Leader
HN	Host Nation
IID	Independent and Identically Distributed
JNLWD	Joint Non-Lethal Weapons Directorate
JNLWP	Joint Non-Lethal Weapons Program
MANA	Map Aware Non-Uniform Automata
MASS	Modular Accessory Shotgun System
M&S	Modeling and Simulation
NLW	Non-Lethal Weapon
NOLH	Nearly Orthogonal Latin Hypercube
OE	Operating Environment
PC	Platoon Commander
PS	Platoon Sergeant
ROE	Rules of Engagement
RSO	Regional Security Officer
SEED	Simulation Experiments and Efficient Designs
SL	Squad Leader
SPMAGTF-CR	Special Purpose Marine Air Ground Task Force - Crisis Response

SPMAGTF-CR-AF	Special Purpose Marine Air Ground Task Force - Crisis Response - Africa
TTP	Tactics, Techniques, and Procedures
U.S.	United States
USAFRICOM	United States Africa Command
USD(AT&L)	Under Secretary of Defense for Acquisitions, Technology and Logistics
USCENTCOM	United States Central Command
USMC	United States Marine Corps
USSOUTHCOM	United States Southern Command

EXECUTIVE SUMMARY

The United States Marine Corps (USMC) established Special Purpose Marine Air Ground Task Force Crisis Response (SPMAGTF-CR) units to serve as a quick reaction force in support of specific combatant commanders. Two key tasks assigned to these SPMAGTF-CRs are to be able to conduct reinforcement of a United States (U.S.) Embassy and to employ a variety of non-lethal weapons (NLW).

The Joint Non-Lethal Weapons Directorate (JNLWD) is the DOD's action arm for all NLW matters pertaining to Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P). One munition employed by the DOD and managed by JNLWD is the XM1116 Extended Range Marking Munition (ERMM). The ERMM is a blunt force munition designed to deter, disable, or stop potential hostile targets. JNLWD has requested support in developing tactics, techniques, and procedures (TTP) for the employment of the ERMM. Additionally, the JNLWD requested an exploration of the ideal maximum effective range of the ERMM to support identifying initial requirements in the procurement of a new similar munition.

Using agent-based simulation (ABS), and state-of-the-art Design of Experiments (DOE), we explore the best employment options for the ERMM for a USMC infantry platoon conducting a dismounted patrol in support of a U.S. Embassy. Using the ABS modeling environment Pythagoras, a scenario was developed taking place in the city of Abuja, Nigeria. Figure ES-1 depicts the initial conditions of a given simulation. The Marine patrol begins in the landing zone, marked in the bottom right, and follows a predesignated route (blue line) to the U.S. Embassy. Interspersed throughout the "game board" are civilians and enemy forces.

Figure ES-1. Initial Simulation Set-up. Adapted from Google Earth (2016).

Using the nearly orthogonal Latin hypercube (NOLH) DOE methodology 204 design points were generated using three factors. The factors for the simulation were: (1) ERMM maximum effective range, (2) number of civilians in the scenario, and (3) NLW case. Twelve NLW cases were developed detailing how many NLWs and their respective locations within the patrol using USMC doctrine. The NOLH was applied to the first two factors, resulting in 17 design points, which were then crossed with all 12 NLW cases, resulting in the 204 design points. Using the Simulation Experiments and Efficient Designs (SEED) Centers computing cluster 8,160 simulated missions were run. To support JNLWD's request to explore the ideal maximum effective range of the munition, an additional 1,700 simulated missions were run using 14 NLWs and 300 civilians within the scenario and varying only the maximum effective range of the NLW.

The key insights from the analysis are:

- Regardless of the population density, adding NLWs to the scenario will always decreases the average number of lethal shots fired.
- Increasing the maximum effective range of the NLW decreases the average number of lethal shots fired in all three population density categories.

- The most significant decreases in the average number of lethal shots fired occur when adding five or 14 NLWs to the scenario. Five NLWs in a patrol means each squad leader (3), the platoon sergeant, and platoon commander have a NLW. Fourteen NLWs results in the same five individuals having a NLW and adding one to each fire team within the patrol.

- In a low population density, the ideal number of NLWs in a dismounted patrol is at least five. In a high population density, the ideal number of NLWs increases to 14.

Figure ES-2 was developed to show the results of the focused study on maximum effective range. After analyzing the results of the 1,700 simulated missions there is a clear “knee in the curve” where you no longer generate significant reductions in the average number of lethal shots fired. The area shaded in red in Figure 2 represents the standard error for the estimates of the average number of lethal shots fired. The grey dots are the raw data from the 1,700 simulated missions. The darker the dots the more observations there were at those values. Although there is variation in any given simulated mission, the standard errors for the estimates of the mean are very small and represented by the red shaded area along the curve. The ideal maximum effective range for the ERMM or like munition is 75 meters.

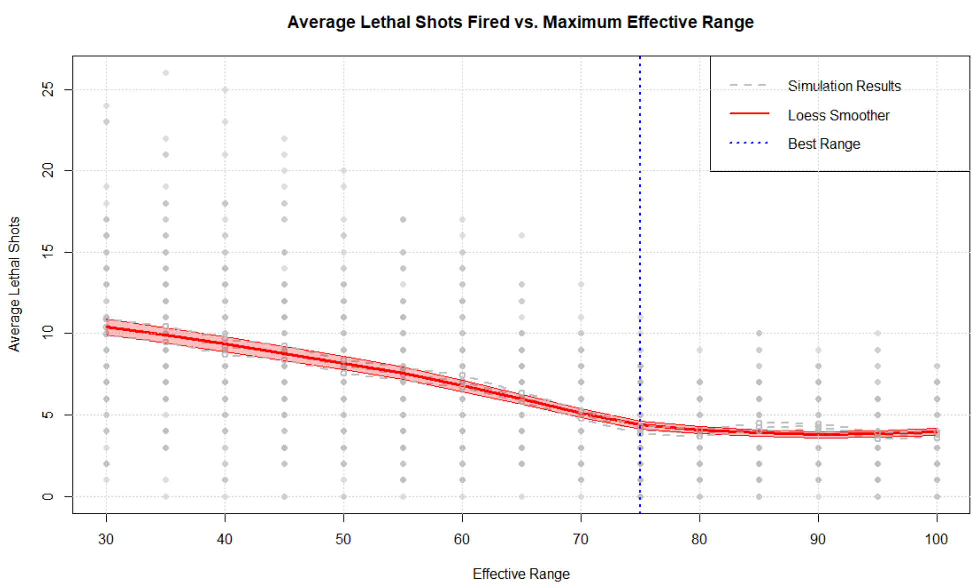

Figure ES-2. Results of Varying Effective Range in a Focused Scenario with Raw Data

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I. INTRODUCTION

> The U.S. hegemon needs to be able to control the geographies of the global commons. Americans will have to be free to use the sea, the air, space, and cyberspace at will, all the while being able to deny such operational liberty to some other states and political entities.
>
> —Dr. Colin Gray
> *After Iraq: The Search for a Sustainable National Security Policy*

A. THE NEW NORMAL OPERATING ENVIRONMENT

An ever-changing global environment has given birth to a new operating environment within the Department of Defense (DOD), which is being branded the "New Normal." Per Steward's article (2010), "In terms of defense, the world is now one of friction between the current and conventional and the emerging and asymmetrical—a friction that parallels the dueling paradigms now vying for DOD's attention" (44). The DOD cannot simply focus on preparing for conventional warfare. The past 15 years of wars in Iraq and Afghanistan have proven that the threat against the United States (U.S.) is not solely that of state actors, but non-state actors as well. The "New Normal" operating environment is one in which the DOD must dominate four domains: sea, air, space, and cyberspace to ensure national interests and security are maintained (Steward 2010).

The September 11, 2012, attack on U.S. diplomatic facilities and personnel in Benghazi, Libya resulted in the DOD authorizing the United States Marine Corps (USMC) to establish a task organized unit dubbed, Special Purpose Marine Air Ground Task Force Crisis Response (SPMAGTF-CR). In Feickert's Congressional Report (2014), he states that in 2013 the first iteration of this unit was a "550 person Marine crisis-response centered on a reinforce Marine rifle company, six MV-22B Ospreys and two KC-130J Hercules tanker planes" (10). The original SPMAGTF-CR was organized under the commander of U.S. Africa Command (USAFRICOM) with forces located in Morón Airbase in Spain and Naval Air Station Sigonella (Feickert 2014). A year after the creation of AFRICOM's SPMAGTF-CR, the Marine Corps established crisis response

elements aligned to U.S. Central Command (USCENTCOM) and U.S. Southern Command (USSOUTHCOM). Each of the regionally aligned SPMAGTF-CRs are tailored to meet the requirements of their assigned combatant commander. Feickert (2014) states that SPMAGTF-CR-Africa (SPMAGTF-CR-AF) and SPMAGTF-CR-Central Command both provide an embassy reinforcement capability that is not reliant on U.S. naval ships and can fly quickly to a designated location.

SPMAGTF-CR-AF's embassy reinforcement capability is designed to quickly reinforce an embassy or diplomatic facility at the request of the U.S. Ambassador. This force is trained on fixed site security, the employment of lethal and non-lethal weapon (NLW) systems, riot control, and other mission essential tasks. This force is designed to be called upon in a semi-permissive environment to bolster security at a given location. The SPMAGTF staff works closely with USAFRICOM and the U.S. Department of State (DOS) to ensure the force is brought in before a situation deteriorates and the force is unable to reach the diplomatic location.

B. EMERGENCE OF NLW IN SUPPORT OF "NEW NORMAL" MISSIONS

On July 1, 1997, the Joint Non-Lethal Weapons Directorate (JNLWD) was established to support the DOD Executive Agent for NLWs with the day-to-day management of the DOD NLWs program (Department of Defense [DOD] 2016). NLWs are defined as "weapons, devices, and munitions that are explicitly designed and primarily employed to incapacitate targeted personnel or materiel immediately, while minimizing fatalities, permanent injury to personnel, and undesired damage to property in the target area or environment" (DOD 2013, 12). NLWs can support ground forces in determining the intent of local nationals without having to use lethal munitions. This unique capability has the potential to deescalate a possibly volatile situation. The Commandant of the Marine Corps (CMC) is tasked as the DOD's Executive Agent for NLWs.

The current CMC, General Robert Neller, writes "the NLW program will continue to invest in the technology and research of non-lethal capabilities to enhance readiness and minimize civilian casualties in support of U.S. military strategy" (2016, 1).

General Neller recognizes the utility of NLWs and how their employment can have an impact on DOD forces operating in the "New Normal" environment. In the same planning guidance, Neller (2016) writes "The complex security environment commonly referred to as the 'New Normal' yields new challenges and demands varying, discriminating and proportionate capabilities for our warfighters" (1). Figure 1 is a depiction of the Joint Non-Lethal Weapons Program (JNLWP) structure within the DOD. The Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) has principal oversight of the JNLWP and supervises the acquisition and procurement process of emergent NLW systems.

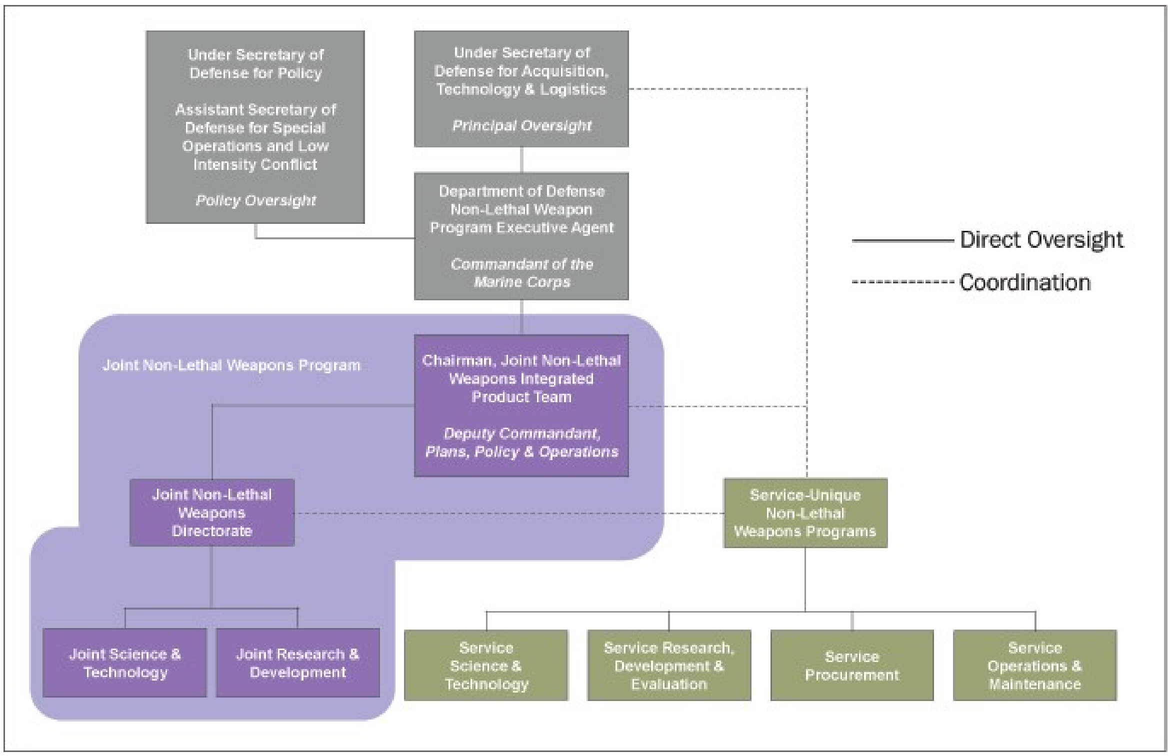

Figure 1. JNLWP Structure within the DOD. Source: Neller (2016, 3).

Employment of NLWs can be traced back to U.S. actions when withdrawing from Somalia in 1994. Lieutenant General Anthony Zinni, the Task Force commander assigned to oversee the withdraw, stated "Our experience in Somalia with non-lethal weapons offered ample testimony to the tremendous flexibility they offer to warriors on

the field of battle" (Scott 2007, 7). Since their employment in Somalia, NLWs have been employed by DOD forces in Kosovo, Iraq, Afghanistan, Haiti, and Cuba (LeVine and Rutigliano 2015, 244–245).

C. PROBLEM STATEMENT

When operating in the "New Normal" environment DOD forces must be able to quickly and effectively distinguish individuals with hostile intent, individuals who are merely innocent civilians, and everything in between. One method of differentiating these two groups of individuals is the employment of a NLW system. The DOD employs a multitude of NLWs aimed at two specific areas: anti-personnel and anti-materiel. The JNLWD is responsible for all facets of the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P) with respect to NLWs within the DOD (DOD 2013). The CMC is specifically tasked to "Recommend policy, as appropriate, for the employment and deployment of NLW to the Under Secretary of Defense for Policy" (DOD 2013, 9). Determining the best Tactics, Techniques, and Procedures (TTP) for NLWs will aid the JNLWD in the development of training packages and serve as a substantiating record for deployed forces desiring to employ NLWs in a semi-permissive environment. This research focuses on two specific areas in developing TTPs.

1. In a dismounted patrol in an urban environment, how are NLWs best employed? More specifically, how many NLWs should be in the patrol and where should those weapon systems be located in the patrol?

2. In an urban environment, what is the best maximum effective range for a blunt force munition?

D. SCOPE

The DOD has been employing NLWs for over two decades. Their success across the range of military operations is documented and NLWs have proven to be a successful capability employed by the DOD (Neller, 2016). As technologies continue to advance, so to do the capabilities of NLWs. One method for evaluating the effectiveness of NLW capabilities is agent-based simulation (ABS) (Wittwer 2006). This research uses techniques rooted in ABS, probability, design of experiment (DOE), and data analysis to

effectively simulate and analyze an embassy reinforcement scenario utilizing current NLWs. Following the design of experiment and execution of multiple simulation experiments the focus turns toward analysis of the results. The emphasis of the analysis is to assess the viability of the model to determine if NLWs are effective in the scenario and how to best employ a specific NLW system in the given scenario. Our objective is to provide the JNLWD with a recommendation about the best employment of a specific NLW system in an embassy reinforcement scenario. These findings can help shape the TTPs for NLW as well as doctrine.

E. THESIS ORGANIZATION

To best develop TTPs for the employment of NLWs, this research first chose a weapon system currently employed by the DOD and developed a representative semi-permissive scenario in which to explore its employment. With the given weapon system and scenario, an agent-based simulation is utilized to determine the best TTPs for the employment of the specific weapon system in the chosen environment.

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II. THE OPERATIONAL ENVIRONMENT, NLW SELECTION, AND THE MODELING ENVIRONMENT

> The complex security environment commonly referred to as the "New Normal" yields challenges and demands varying, discriminating and proportionate capabilities for our warfighters. The applicability of NLW across the DOD is only growing.
>
> —General Robert B. Neller, USMC
> DOD NLW Executive Agent
> *Non-Lethal Weapons Program Executive Agent Planning Guidance 2016*

A. THE OPERATIONAL ENVIRONMENT

Joint Publication 3–35 (*Deployment and Redeployment Operations*) describes three types of operating environments (OEs) that are recognized by the DOD: permissive, uncertain, and hostile (U.S. Joint Chiefs of Staff 2013, I-1–I-2).

> An uncertain environment is an OE in which Host Nation (HN) forces, whether opposed to or receptive to operations that a unit intends to conduct, do not have totally effective control of the territory and population in the intended operational area. In this situation, entry operations during deployment are generally unopposed but could be opposed at any point during the deployment by forces or individuals not under HN control. (U.S. Joint Chiefs of Staff 2013, I-1)

For purposes of clarity, an uncertain OE is synonymous with a semi-permissive environment. The uncertainty and ability for the environment to quickly escalate to a hostile environment is a critical aspect to "New Normal" operations.

The scenario developed for this research is within the semi-permissive OE. A key task to SPMAGTF-CR forces operating in "New Normal" conditions is to conduct an embassy reinforcement if requested by the DOS. Putting U.S. forces on foreign soil is a decision which can quell potential turmoil; but there also exists a real chance that it could do quite the contrary and add "gasoline to the fire." A region which has gained DOD and media attention in recent years is the continent of Africa. With limited infrastructure, weak state institutions, Violent Extremist Organizations, Al Qaeda (AQ), and multiple

recent crises (e.g., South Sudan, Libya, Egypt, etc.), the continent of Africa has the potential to impact the globe in the future (United States African Command 2014).

The DOD has combatant commanders aligned to regional areas throughout the globe. USAFRICOM has responsibility for the continent of Africa. Guided by the National Security Strategy, Presidential Policy Directives 13, 16, and 23, and DOD guidance, the mission of USAFRICOM "in concert with interagency and international partners, builds defense capabilities, responds to crisis, and deters and defeats transnational threats to advance U.S. national interests and promote regional security, stability, and prosperity" (United States African Command 2014, 4).

A simple Internet search provides the location of the U.S. Embassy in any country where one exists. For our analysis scenario, the U.S. Embassy in the city of Abuja, Nigeria is used. Nigeria has significant potential for instability, which may lead the U.S. Ambassador to Nigeria to request a reinforcement, making it an excellent choice to serve as the nation the scenario takes place in. In 2015, the author deployed with the Command Element for SPMAGTF-CR-AF and Nigeria was a nation that we constantly monitored due to its potential for turmoil. One of the key factors for the potential instability is due to the terrorist organization Boko Haram operating within the country (Taylor 2013). Boko Haram has committed numerous acts of terrorism and has ties to AQ (Taylor 2013). Figure 2 shows the country of Nigeria, major cities to include Abuja, and a map of where Nigeria is on the African continent.

Figure 2. Map of Nigeria. Source: Enchanted Learning (2016).

The U.S. Embassy is generally located within the capital city of a nation. When conducting an embassy reinforcement, the platoon deploying in support of the DOS would likely have to transit an urban environment, as most nations' capitals are heavily populated. The nature of an urban environments forces interaction with the local population. How the local population will view a reinforcement force varies based on the nation, situation, and many other factors. When a force is called to reinforce an embassy, it means that there are indications and warnings of potential violence and any negative interactions with the local population may exacerbate the situation.

The considered scenario starts with an SPMAGTF-CR-AF embassy reinforcement platoon having just landed in an open area in the city of Abuja. The force is approximately three kilometers away from the U.S. Embassy and will conduct a dismounted patrol through the urban environment. The ideal employment of the SPMAGTF-CR reinforcement platoon is into a semi-permissive or permissive environment when indications and warnings show potential for hostilities. The decision to request an embassy reinforcement lies with the U.S. Ambassador to that nation and,

once requested, the Marine platoon will work directly for the Regional Security Officer (RSO). The RSO "serves as the primary advisor to the Chief of Mission on all security matters by developing and implementing security programs that shield U.S. missions and residences overseas from physical and technical attack" (U.S. Department of State 2017, para. 2). While conducting the movement to the embassy the patrol must interact with local nationals who are conducting their lives as normal. As is the case in many countries around the globe, the sight of U.S. Marines may cause mixed feelings within the population. The Marines will interact with the local population while transiting the battlespace with a goal of safely making it to the embassy without any kinetic interactions. They will be armed with lethal and non-lethal munitions and follow specific Rules of Engagement (ROE).

B. NLW SELECTION

Given the scenario described, providing the embassy reinforcement force with a tool to interact and engage with the local population other than verbal / non-verbal communication and lethal means could prove beneficial to the force's security and protection. NLWs serve as a great transitional mechanism between verbal communication and lethal weapons. In this scenario, the embassy reinforcement force has a NLW capability, adding an additional layer to the escalation of force methods the unit can employ before having to use lethal weapons.

The JNLWD maintains cognizance of dozens of NLWs employed throughout the DOD. The XM1116, shown in Figure 3, Extended Range Marking Munition (ERMM) is a non-lethal blunt impact and marking munition fired from a 12-gauge shotgun. This munition has been in the DOD arsenal for almost a decade and is an advancement on the XM1012 munition previously used. The XM1116 provides a greater effective range (30m to 50m) compared to its predecessor (10m to 20m) and marks an individual with ink for future identification of an individual who was previously seen as a potential threat (Correa 2016). The purpose of the ERMM is to provide blunt force trauma to stop, disorient, or deter a potential threat (Correa 2016).

Figure 3. XM1116 Extended Range Marking Munition.
Source: Correa (2016).

The ERMM can be fired from a Mossberg 500/590, shown in Figure 4, and the Modular Accessory Shotgun System (MASS) M26, shown in Figure 5 (Correa 2016). The Mossberg 500/590 is a standalone 12-gauge shotgun and the MASS is a shotgun attachment that can be mounted onto the M16 or M4 currently employed by the DOD. The MASS allows DOD forces to quickly transition between lethal and non-lethal capabilities without having to switch to a different weapon system. Having the lethal and non-lethal capability on one weapon system also reduces the amount of weight DOD personnel must carry and increases their mobility.

Figure 4. Mossberg 500/590. Source: Jane's IHS Markit (2016).

Figure 5. MASS. Source: *Wikipedia* (2016).

The ERMM was chosen as the NLW for this scenario due to its modular employment, tactical capabilities, and the psychological effects associated with bringing a weapon into a foreign country. The unique ability for the MASS to be added to a generic assault rifle provides the individual carrying it the ability to quickly transfer to that system. Although access to the Mossberg standalone weapon system requires switching the weapon, an individual utilizing it does not require an excessive amount of time to switch between the Mossberg and an assault rifle. Regardless of the employment method of the ERMM (MASS or Mossberg) the weapon system required to discharge the munition has a small profile and appearance of a personal weapon when compared to many machine guns, grenade launchers, and higher caliber weapons systems. This smaller profile serves forces well when viewed by a local population. Often larger weapons carry the stigma that a force is trying to take over an area, while a weapon with a small profile has the appearance of self-protection. Additionally, the capabilities of the ERMM are clearly defined by the JNLWD, allowing the system to be modeled more easily.

C. THE MODELING ENVIRONMENT

1. Modeling and Simulation

The Defense Modeling and Simulation Office (DMSO) defines a model as “A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process” (DOD 1998, 138). One method for conducting analysis of a

scenario and possible outcomes is through the process of simulation. Per DMSO and the *DOD Modeling and Simulation (M&S) Glossary* a simulation is a “method for implementing a model” (157). More clearly, a simulation is an attempt to replicate or imitate a real system or process. Simulations are particularly valuable analysis methods for studying complex scenarios in which physical experiment is infeasible or costly (Lucas et al. 2015). Often this is done with computers and other technologies. When modeling and simulation are combined via an experiment the resulting data can be analyzed to provide insights. There are many types of simulation used within the DOD, with two of the most common being discrete-event simulation (DES) and ABS. The DOD uses simulation models in support of training and decision making (Cioppa, Lucas, and Sanchez 2004, 174). M&S is employed to test operational plans, develop force structure plans, and make decisions about equipment system procurement. DES involves a specific sequence of events occuring at a particular instance in time; i.e., it is an event driven simulation. Tom Lucas gave a lecture titled “An Overview of Community Models, Resources, Key Issues, and Vocabulary” in October 2016 at Naval Postgraduate School. In his lecture he discusses the continued debate about the true definition of ABS; however, for this study ABS is defined as a representation of a system where individual autonomous agents (software objects) interact and organize with each other.

2. Selecting the Type of Simulation

To produce the best results, it is critical to carefully select the type of simulation being conducted and a proper modeling environment. The first step in selecting the best simulation and environment is to clearly define what needs to be modeled. Table 1 shows items identified as needing to be modeled and desired attributes of each specific item given the scenario developed and NLW selection.

Table 1. Attributes to Be Modeled

People	Behavior	Weapons Possessed
Marines (Blue Force)	Adherence to Chain of Command, Unit Integrity, Communication, Adherence to ROE	Voice Commands, Lethal, Non-Lethal
Civilians (Blue Friendly)	Full autonomy, Possibility of “mob mentality,” React to Blue and Red weapons	Rock (instigation method)
Civilians (Red Friendly)	Full autonomy, possibility of “mob mentality,” React to Blue and Red weapons	Rock (instigation method)
Antagonists (Red Force)	Spectrum of “badness,” autonomous, communication with other Red Force	Voice, Rock, Lethal
Weapons	**Desire**	**Effects**
Voice Command	Deter or instigate those “hit” by voice	Change to sidedness, stop, move away
Lethal Weapon	Produce lethal effects on target	Has probability of kill, probability of hit, results in agent “death”
NLW	Incapacitate a target, identify possible hostile actor	Has probability of kill, probability of hit, results in agent incapacitation with certain probability and duration
Rock	Instigate the Blue Force to illicit reaction	Causes Blue Force to react with lethal or non-lethal means
Terrain	**Design**	
Road Network	Open Movement, Line-of-Sight, Alley ways	
Buildings	Provide cover and concealment, no agents enter, obstruct sight	
Vegetation / Open	Open movement throughout all areas except buildings, Clear line of sight	

Charles Macal from the Center for Complex Adaptive Systems Simulation maintains a list of desired features that a problem should have to make it a suitable candidate for ABS. The list includes having a goal of modeling behaviors from a diverse population, the existence of dynamic relationships between agents, a requirement for spatial and geo-spatial aspects, agents are required to cooperate, collude, or form organizations, and “when the past is not a predictor of the future” (quoted in Siebers, et al. 2010, 205). Based on the criterion identified in Table 1 and the list introduced by Macal, ABS was chosen as the best form of simulation to use. The need for interactions between agents, time and space requirements between agents, weapons, and the terrain, and the need for agents to learn were the key factors in deciding on ABS.

3. ABS Employment within the DOD

The DOD has a history of using ABS to provide insights into complex problems. ABS have been used in support of developing leading edge DOD acquisition programs to include the Future Combat System and the unmanned surface vehicles (Cioppa, Lucas, and Sanchez 2004). Other entities within the DOD have used ABS to model insurgencies and develop resource allocation strategies to counter the insurgencies. (Huddleston, Learmonth, and Fox 2008). In their research Huddleston, Learmonth, and Fox (2008) used ABS to create a modified predator-prey model where insurgents, civilians, and military forces interact, and each agent's actions cause the other agents to react. ABS provides the DOD with many insights about complex problems and continues to be a useful tool in supporting decision makers.

4. Selecting the Modeling Environment

After deciding an ABS would be the most suitable type of simulation to produce quality results; the next critical decision was the environment in which to model. Like choosing the best type of simulation; selecting the best modeling environment was based on criteria such as ability to show sidedness, model libraries, the coding language, and interoperability with geographic information systems. Four ABS modeling environments: Map Aware Non-uniform Automata (MANA), Pythagoras, Netlogo, and Repast were selected for comparison. Table 2 is a comparison of each of the selected modeling environments based on desired characteristics.

Table 2. Modeling Environment Comparison

Environment	Language	GIS Capable	Triggers	Model Library	Sidedness
Pythagoras	GUI Based	No	Yes	Past Theses	Yes (255[3] Options)
Mana	GUI Based	Yes	Yes	Past Theses	Yes (3 Options)
Netlogo	Netlogo	Yes	Rule Generated	Yes	Rule Generated
Repast	Python/Java	Yes	Rule Generated	Yes	Rule Generated
Environment	**Communication**	**Weapon**	**Marking Wpn**	**Waypoints**	**Multiple Personalities**
Pythagoras	Yes	Yes	Yes	Yes	Yes
Mana	Yes	Yes	No	Yes	Yes
Netlogo	Rule Generated	Rule Generated	Rule	Yes	Yes
Repast	Rule Generated	Rule Generated	Rule	Yes	Yes

Table 2 was critical in determining that Pythagoras would be the most effective modeling environment for modeling NLWs in an embassy reinforcement scenario. Pythagoras and MANA were the top two candidates due to their graphical user interface, ability to have a "marking" weapon, and repository of past models. However, Pythagoras's ability to incrementally adjust the sidedness of an individual agent was the determining factor to its selection.

D. PYTHAGORAS

1. Pythagoras Background

Northrop Grumman developed Pythagoras in support of the USMC and delivered version 1.0 in April 2002 (Bitnas, Henschied, and Middleton 2006). Pythagoras was developed due to a demand for an ABS environment that could incorporate soft rules (i.e., "Don't shoot until the enemy gets close") and allow the individual agents the ability to "shoot, move, and communicate" with each other (Bitnas, Henschied and Middleton 2006).

Pythagoras was created to fill a void in existing combat models identified in the following list (Wittwer 2006):

- **Nonlinearity**—Effects of small input changes;
- **Intangibles**—Human factors such as leadership, reasoning and logic;
- **Co-evolving Landscape**—All agents anticipate actions and base their decisions on anticipation.

2. Pythagoras Modeling Combat

The combat environment is not solely dependent on the physical world, but rather it incorporates the physical aspect with human factors (which motivate or deter individuals to take certain actions) and leadership (the ability to inspire, motivate, integrate, command, and employ weapon systems and personnel to attain a goal) (Northrop Grumman Space & Mission Systems Corp 2008, 1–1). Pythagoras was developed to incorporate all three factors into an ABS capable of simulating the combat environment depicted in Figure 6.

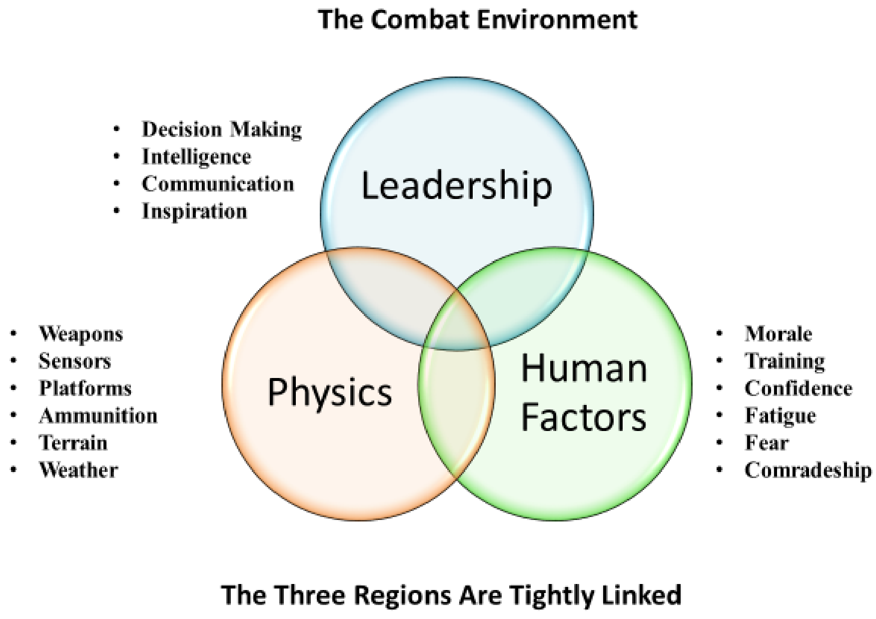

Figure 6. The Combat Environment. Source: Northrop Grumman Space & Mission Systems Corp (2008, 1–1).

Pythagoras uses fuzzy logic to take simple binary concepts and applies a scaled continuum to each level (Northrop Grumman Space & Mission Systems Corp, 2–1). The fuzzy logic application allows agents within the simulation to slowly alter their sidedness, desire to engage a target, and many other individual and group characteristics which occur in combat. Below are the unique set of capabilities Pythagoras provides in ABS from its user manual:

- Incorporates ***soft rules*** to distinguish unique agents;
- Uses ***desires*** to motivate agents into moving and shooting;
- Includes the concept of ***affiliation*** (established by ***sidedness***, or color value) to differentiate agents into members of a unit, friendly agents, neutrals, or enemies;
- Allows for behavior-changing events and actions (called ***triggers***) that may be invoked in response to simulation activities;
- Introduces generic attributes that can be changed, measured, and used to control or influence behavior;
- Adds generic resources that can be expended and replenished;
- Retains traditional weapons, sensors, and terrain (Northrop Grumman Space & Mission Systems Corp 2008, 1–3).

These unique capabilities make Pythagoras the best environment to conduct an ABS modeling NLW in a semi-permissive urban environment. The ability to control the "spread" (initial distribution of random decision variables) allows Pythagoras users to instantiate very homogenous or quite heterogenous agents (Henscheid, Middleton, and Bitinas 2006). Using soft rules, affiliations, triggers, and scaled changes to sidedness enables the embassy reinforcement scenario can be modeled more realistically. Additionally, Pythagoras is an ABS which is capable of being used to "data farm." This means the software has been written to automate the process of running designed experiments on a computing cluster, therefore allowing the running of multiple simulations simultaneously.

Pythagoras is a time-step based model. This means that at every time step each agent goes through a series of "checks." Before the simulation moves on to the next time-

step every agent in the simulation will complete the same process. Figure 7 shows the process that every agent within Pythagoras completes prior to the time moving forward. The simulation ends once the allotted number of time steps have taken place. The simulation for this scenario lasts for 1000 time steps. Each time-step is equivalent to one second, therefore modeling a scenario of almost 17 minutes. This allows the Marines time to transit through the scenario toward the embassy.

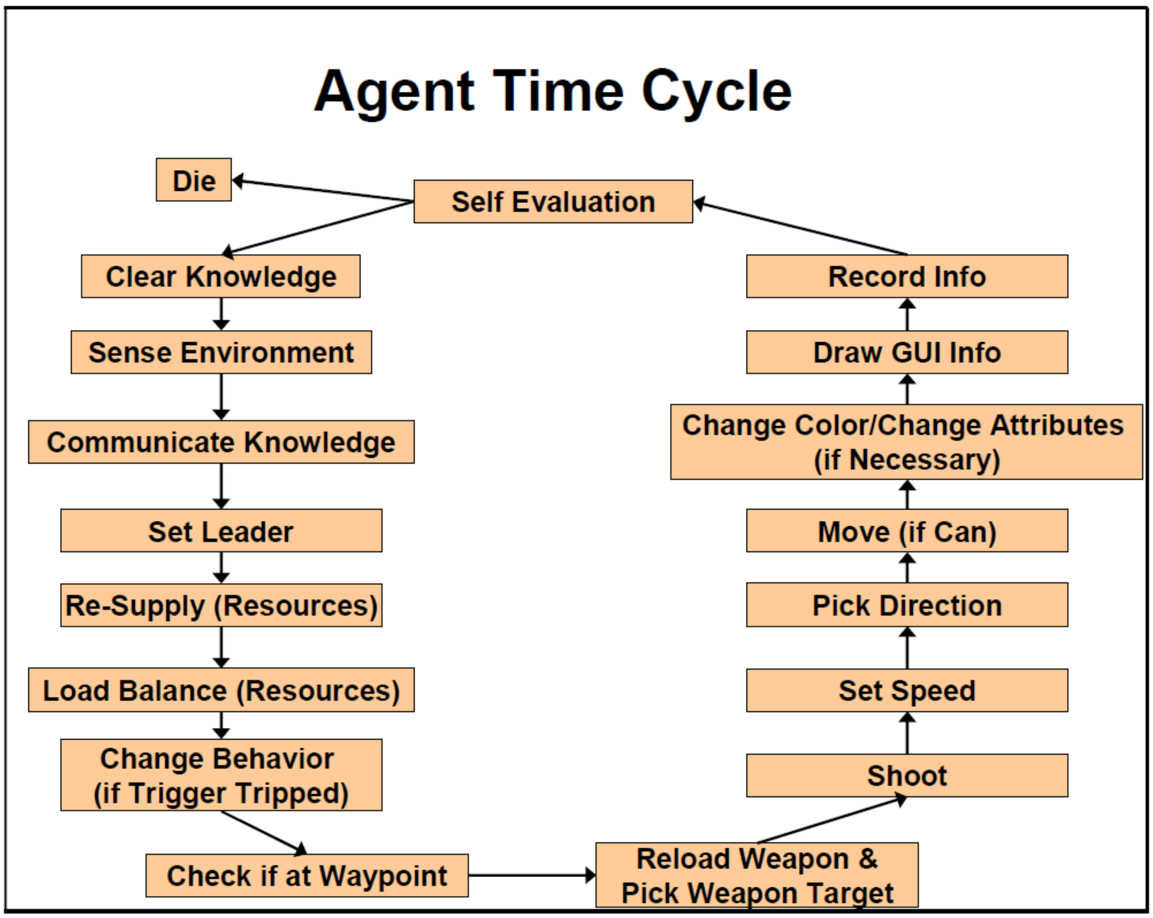

Figure 7. Pythagoras Agent Time Cycle. Source: Northrop Grumman Space & Mission Systems Corp. (2008, 3–2).

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III. THE MODEL

> During the 1950s, I decided, as did many others, that many practical problems were beyond analytic solution and that simulation techniques were required.
>
> —Harry Markowitz
> American Economist and 1990 Nobel Prize in
> Economics Winner (Nobel Media 2017)

A. PYTHAGORAS CHARACTERISTICS

Pythagoras provides the user with many characteristics from which to select and modify when building a simulation. The list below outlines the general areas to be modeled within Pythagoras:

- Overview
- Terrain
- Weapons
- Sidedness
- Sensors
- Communication
- Agent
- Attribute Changer
- Alternate Behavior
- Measures of Effectiveness

Each of these areas are critical to creating a simulation environment that behaves as close to reality as possible. For this study, all areas, except for communication, were used. Areas such as the terrain and agents are explained in further detail later in this document. For more information on each of the characteristics reference their respective chapters in the *Pythagoras User's Manual*.

1. Weapons

Direct and area fire weapons can be created in Pythagoras. Associated with each weapon is a probability of kill, probability of hit, fire rate, and rounds of ammunition. The Pythagoras User's Manual advises the user to think of weapons as influence tools (Northrop Grumman Space & Mission Systems Corp 2008, 8–1). Weapons within Pythagoras can serve as literal weapons, inflicting damage, but can also be used to represent food, medicine, fuel, or intangibles such as encouragement, fear, or affiliation (Northrop Grumman Space & Mission Systems Corp 2008, 8–1).

2. Color and Sidedness

This feature allows the user to affiliate agents with other agents within the simulation. The sidedness of each agent is defined by a combination of red, blue, and green, each on a scale from 0 to 255, as well as a definition of how close or far away (in color space) an agent must be to be considered a friend, neutral, or enemy. Weapons or specific simulation events can be made to impart color changes upon agents. Because of that, sidedness can change as the simulation runs, and can be used to cause agents to act differently toward other agents based on whose side they are on at that time. This attribute is critical to this study as the sidedness of the local population is the fulcrum of a semi-permissive environment turning kinetic or peaceful.

3. Attributes and Attribute Changers

In addition to the possibility for weapons or simulation events to cause color changes, they can also be made to increase or decrease the amount of "attributes" that agents have. There are 10 generic attributes that each agent can possess, and the quantity of each attribute (if used) can increase or decrease over time. The attribute changer for our scenario serves as a means to represent the ROE for the agents within the model. This allows the user to create thresholds for attributes on an agent which in turn will alter their behavior. An example of this is changing how a Blue agent acts after being hit by a "rock" in the simulation. Prior to being hit the agent would only use his voice "weapon," however, after being struck by a "rock" (weapon used by a different agent), which was made to increase the Attribute 3 value of the Blue target, the Blue agent triggers from that

change in Attribute 3 and subsequently has a propensity to use a NLW. Attribute changers are critical in ensuring that the agents within the simulation abide by user-specified ROEs. In our scenario, a Blue agent using its Loud Speaker "weapon" imparts Attribute 1 upon the target; and using its NLW imparts Attribute 2 upon the target.

4. Alternate Behaviors

Another interesting feature of Pythagoras is the ability to define alternate behaviors. Certain simulation events, or a change in color or attributes, can be associated with an agent leaving its default behavior and gaining a new alternate behavior. An alternate behavior can be something as simple as changing a movement desire (wanting to move toward an enemy) or more complex, such as changing sides and acquiring a new weapon system. This feature was used in combination with color and attribute changers to establish the ROEs within the simulation.

5. Triggers

Certain simulation events, such as being shot at, death of a unit member, knowledge of enemy, color or attribute changes, etcetera, can define a "trigger" such that an agent leaves its default state and goes into a new alternate behavior. The Pythagoras User's Manual outlines 49 possible triggers including arriving at an objective, getting shot at, or having an attribute level greater than a specific threshold (Northrop Grumman Space & Mission Systems Corp 2008, 12–119). The Pythagoras user can make triggers apply just to individual agents, or to all agents within an agent class, or to all members of a unit, or to all mutual friends (Northrop Grumman Space & Mission Systems Corp 2008, 12–121). This capability allows the user to have entire groups of agents react to a given stimulus. The best example of this is a military unit responding to an event with lethal force after they have been engaged with lethal force. In practice, with many ROEs, if one member of a squad is engaged, the entire squad will respond with lethal force. Table 3 shows examples of triggers within the simulation for specific agents.

Table 3. Example Agent Triggers

Agent	Attribute 1	Attribute 2	Attribute 3	Shot At	Friendly Casualty	Redness	Shooting
Blue	N/A	N/A	>99 willing to shoot NLW at high fire rate.	Willing to shoot NLW at low fire rate.	Willing to shoot M4.	N/A	N/A
Civilian Blue-Friendly	>49 will heed Blue Force warning, move away or stay in place. Becomes almost all Blue.	>49 Agent becomes a little more Red based on Normal distribution.	N/A	N/A	N/A	>200 Agent becomes willing to throw rocks. Has propensity to turn all the way Red.	Increased detectability. Agent will “stand out” in a crowd.
Civilian Red-Friendly	>175 Stay in place. Sidedness will change according to distribution.	>49 Agent changes Blue / Red sidedness based on Normal distribution.	N/A	N/A	N/A	>250 Agent willing to pick up AK47 and fire lethal munition.	Increased detectability. Agent will “stand out” in a crowd.
Red	N/A	>49 Agent has been hit by NLW and will fire AK47 if surrounded by sufficient number of Reds.	N/A	N/A	N/A	N/A	N/A

N/A – Not Applicable

B. TERRAIN

1. Location

The scenario is based in Abuja, Nigeria. To add realism and perspective to the scenario, the location of the U.S. Embassy in Abuja and the surrounding area were captured using Google Earth. The left map in Figure 7 is the image extracted from Google Earth with additions highlighting the selected landing zone (red circle) for the embassy reinforcement platoon and the location of the U.S. Embassy (green rectangle). The area depicted is 1700 meters wide by 1100 meters tall. These measurements were carefully selected to allow one pixel in Pythagoras to be equivalent to one meter. The pixel ratio is used to calculate distances and agent speeds in the simulation. One section (two aircraft) of MV-22s requires an area of approximately 100 meters by 50 meters to land. A landing zone was selected by finding an open area, large enough for one section of MV-22 Ospreys to land. The area circled in red is approximately 109 meters from east to west and 90 meters from north to south. Circled in green on the left side of Figure 8 is the location of the U.S. Embassy within the city of Abuja. This location is approximately 2,100 meters (Euclidean distance) from the designated landing zone. Having an image of the area where the simulation is being run allows the user to visually watch the agents walk along "real" streets and alleys. When looking at the graphic, Abuja is densely populated with buildings. Associated with the urban environment is a large population density. Per the Central Intelligence Agency factbook on Nigeria, the population of Abuja is approximately 2.44 million, making it the fourth largest city in the nation (Central Intelligence Agency 2017). This high population and dense urban environment lends itself to the Marines conducting the reinforcement having multiple interactions with the local population along the route.

Left Google Earth image of Abuja Nigeria. Right: same image from Google Earth imported into Pythagoras with polygons, waypoints, and agents added. This image is the "game board" for the simulation.

Figure 8. Abuja, Nigeria. Adapted from Google Earth (2016).

2. Terrain Characteristics

The image on the right of Figure 8 is the city of Abuja as it appears in Pythagoras. Polygons are used to outline the buildings within the city. The buildings obstruct vision and provide perfect cover and concealment for all agents within the model. A key assumption for this simulation is that agents, regardless of affiliation or sidedness, cannot enter the building structures. This assumption forces all agents within the model to interact on the "ground," making the environment two-dimensional. All other areas within the "game board" allow for freedom of movement for all agents. There are other areas within the map which depict wooded areas and a river. Movement boxes and waypoints were created so agents within the simulation will not enter these areas. The blue line on the right half of Figure 8 depicts the route that the Marine platoon will traverse during the simulation to reach the embassy.

C. AGENTS

1. Blue Force (U.S. Marines)

The Blue Force in the scenario is the USMC embassy reinforcement platoon. The platoon consists of 40 Marines. Each Marine has similar triggers, characteristics, sensors, and weapons associated to them. The homogeneity within the Blue Force closely resembles the traits associated with a military force. The weapons, triggers, sensors, and characteristics are described in detail below.

a. Weapons

Each Marine has the potential to be equipped with three "weapons." Every Marine will have the "Loud Speaker" weapon. This is designed to resemble the Marine using his or her voice to address any other agents they interact with. The "Loud Speaker" "shoots" Attribute 1 at its targets. The second weapon possessed by the Blue Force is the shotgun which contains the ERMM, which shoots Attribute 2 at its targets. This weapon system shoots a blunt force munition which is intended to stop, disorient, or deter a threat. The final weapon system that a Blue Force member can have is the M4. This is a lethal weapon system which is standard issue to the embassy reinforcement force.

b. Movement Desires

The mission of the reinforcement force is to get to the embassy to begin supporting the security there. Waypoints have been added to the map; agents move from waypoint to waypoint to reach their final destination. Each member of the Blue Force has the same waypoints, and their main priority is to move along those routes, regardless of engagements with other agents within the simulation.

c. Triggers

The members of the Blue Force have specific triggers which help serve as the ROEs by which they behave. Table 3 identified the triggers and resulting behaviors within the Blue Force. It should be noted that the Blue Force triggers are defined at the unit level. Therefore, if one member of the Blue Force is hit with multiple rocks early in

the patrol and triggers into using the NLW at the high rate of fire, the entire unit will be willing to fire the NLW at the high rate of fire for the remainder of the patrol.

2. Red Force ("Insurgents")

The purpose of the Red Force within the simulation is to serve as an instigator to the Blue Force while trying to coerce the civilians to take their side. Initially in the simulation there are very few Red Forces since the scenario takes place in a semi-permissive environment. Unlike the Blue Forces, the Red Force agents act independently, meaning that triggers and changes in behavior happen only to the specific agent.

a. Weapons

The Red Force is also equipped with a "Loud Speaker" weapon which imparts redness to the individuals it hits. This "weapon" allows the Red Force to attempt to slowly change the sidedness of the civilians within the simulation. Additionally, each member of the Red Force is equipped with an AK-47. Given the semi-permissive environment of the scenario, there are two triggers which must occur before a member of the Red Force is willing to fire their AK-47. The first is that they must be struck by an ERMM. Once they have been engaged by a NLW they must also be near five other Red or mostly Red agents, meaning that they feel sufficient support from the crowd to take action.

b. Movement Desires

Members of the Red Force have a propensity to move toward the Blue Force to maintain visibility and attempt to incite a response from the Blue Force. As their "Loud Speaker" continues to work and change the sidedness of the civilians in the simulation, members of the Red Force also desire to move closer to those individuals to surround themselves with likeminded agents.

3. Civilians

Within the simulation there are two types of civilians: those who are Blue-friendly and those who are Red-friendly. Given the scenario it was determined that if

Marines were going to be conducting an embassy reinforcement, some of the local population would support the Marines, while others may be uncertain about why foreigners are in their country. To account for the wide spectrum of possibilities, these two classes of civilians were created. The Blue-friendly civilians are denoted by a diamond icon, while the Red-friendly civilians are denoted by an X. The civilians have similar behavior, movement desires, and access to weapons. The differences will be described in the following paragraphs.

a. Weapons

Both groups of civilians possess the ability to throw rocks at the Marine patrol. The difference between the two groups is the propensity to throw a rock at a Marine. For the Blue-friendly civilians, their hold fire desire is extremely high and they will only throw rocks at enemies. For a Blue-friendly civilian to throw a rock at the patrol they would have to have their sidedness changed to red from either the Red Force or based on negative interactions with the patrol. Red-friendly civilians initially have a stronger desire to throw a rock. Additionally, if a Red-friendly civilian throws a rock at the Marine patrol, they become a little more red. These civilians also have the potential to pick up an AK-47 if their redness crosses a threshold. Once this action occurs, their rules for firing the AK-47 are the same as the Red Force.

b. Movement Desire

Both classes of civilians have freedom of movement throughout the "game board," however, based on their interactions with Red and Blue Forces how they act may change and differ from each other. When the Blue-friendly civilians are "hit" by the Blue Force "Loud Speaker" one of their triggers are activated. The alternate behavior is instantiated and makes them move away from the patrol and increases their speed; in this behavior, they are "heeding the warning and moving away." Additionally, they become undetectable to the Blue Force, so no further efforts are used on that agent. The Blue-friendly civilians are also susceptible to the Red Force's "Loud Speaker." The Red voice will affect the agent with some variability, and turn the agent more red or blue based on a user-specified distribution. The Red-friendly civilians react differently to the Blue

Force's "Loud Speaker." Like the Blue-friendly civilian's reaction to the Red's voice, the Red-friendly civilians have the potential to turn red or blue based on a user-specified distribution when hit by the Blue voice. The Red voice will impact the Red-friendly civilians by adding a small amount of redness every time they are struck. Both classes of civilians are susceptible to the NLW and if struck will be "suppressed" and thus remain in place and unable to shoot for a duration of 30 time steps which is equivalent to 30 seconds in the simulation.

c. Sidedness

Civilians within the simulation begin with either a little more red or a little more blue. This feature allows the civilians to show favoritism toward the Red or Blue Force while interacting. This closely resembles what a Marine embassy reinforcement force would encounter in an actual reinforcement. Many times, when a force is being called to conduct a reinforcement, some of the population wants the force to be there (initially more blue than red) while others are less pleased that a foreign military force is in their country (initially more red than blue). The initial color, and thus side, of the civilians is a starting point for each individual agent and it will change stochastically based on the interactions with other agents within the simulation. A Blue-friendly civilian can turn into a fully red agent willing to fire an AK-47 at the Blue Force depending on the interactions of that agent during the simulation.

D. MODELING ASSUMPTIONS

Every model incorporates assumptions and the model built in Pythagoras for this scenario is not different. Assumptions are made to give the user the ability to continue to progress forward while modeling the "real world" as closely as possible or necessary. This section outlines a few of the critical assumptions which were made in this model. A full list of assumptions can be found in Appendix 1.

1. Communication

Communication between agents of the same class has been assumed to be instantaneous and "perfect." This assumption allows for all members of the Red Force or

Blue Force to gain immediate situational awareness from other members of the class at each time step. If the first member of the patrol is struck with a rock all members of the patrol will act the same and be willing to fire the NLW at the slow fire rate if they possess the weapon system. This happens instantaneously in the model but would take time in a real situation.

2. Red Force Lethality

If a member of the Red Force is ever triggered into firing their AK-47, the probability of kill of that weapon system on the Blue Force is 1.0 (perfect). Thus, every round which is fired from the AK-47 causes a kill on a Blue Force agent. This assumption of immediate and perfect lethality was created to serve as a ROE for the Blue Force. The ROE in this situation would have the Marines only respond with lethal force if they are fired upon first. This is modeled by having a trigger for the Blue Force to respond with lethal force only if there is a blue casualty. The assumption that the Red Force always creates a casualty with their AK-47 most closely replicates this situation.

3. Dimensionality of Structures

A critical assumption within the simulation is that no agents can enter the buildings. This results in all buildings within the simulation providing cover and concealment to all agents. This assumption also removes the third dimensions for the agents to consider. A patrol through a city is continuously monitoring in all directions, to include windows, roofs, and balconies of tall structures. Modeling this within Pythagoras is extremely challenging and would require more time than is available for this study.

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IV. DESIGN OF EXPERIMENTS AND SIMULATION SETUP

> Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation, and eventually build a structure which has no relation to reality
>
> —Nikola Tesla
> American Electrical Engineer and Physicist, July 1934
> (Quoted in Usvat 2017)

A. VARIABLES OF INTEREST

Variables of interest for this thesis are also called factors. Three factors were explored in support of this study aimed at answering the research questions presented earlier. Table 4 shows the factors used during the DOE.

Table 4. Design Factors

Factor #	Factor Name	Minimum Value	Maximum Value
1	NLW Location Case	1	12
2	NLW Max Effective Range (meters)	30	75
3	Number of Civilians	20	500

1. NLW Location Case

To best explore the question of how many NLWs are needed and where the NLWs should be placed in the patrol, a set of plausible cases were developed and numbered to serve as a factor in the experiment. To effectively develop these cases, each agent within the patrol was numbered USMC 1 through USMC 41 depending on its location within the patrol. According to Marine Corps Reference Publication 5–12D, a basic USMC infantry platoon consists of 43 Marines comprised into three squads of 13 Marines, with each squad containing three fire teams of four Marines (Headquarters United States Marine Corps 1998, 4–7). Forty-one Marines were used as agents in this study due to personal experience while working in support of SPMAGTF-CR-AF. This number is based on the capability

and capacity of aircraft used in support of the embassy reinforcement mission. Personal experience and conversations with multiple USMC infantry officers were used when developing the cases. Table 5 describes each case, identifying who has a NLW, the location in the patrol, and total NLWs for that case in the patrol.

Table 5. NLW Cases

Case #	Cases	Location (1 first, 41 last)	# NLW
1	Baseline: No NLW	N/A	0
2	Front-Back (FB)	1,41	2
3	SL	5, 18, 32	3
4	FB, Platoon Commander (PC), Platoon Sergeant (PS)	1, 27, 36, 41	4
5	SL, PC, PS	1, 27, 36, 41	5
6	FB, SL, PC, PS	1, 5, 18, 27, 32, 36, 41	7
7	Fire Team Leaders (FTL)	3, 8, 12, 16, 21, 25, 30, 35, 40	9
8	FTL, Squad Leader (SL), PC, PS	3, 5, 8, 12, 16, 18, 21, 25, 27, 30, 32, 35, 36, 40	14
9	FB, FTL, SL, PC, PS	1, 3, 5, 8, 12, 16, 18, 21, 25, 27, 30, 32, 35, 36, 40, 41	16
10	2 Per FT, SL, PC, PS	2,3,5,7,8,11,12,15,16,18,20,21,24,25, 27,29,30,32,34,35,36,39,40	23
11	FB, 2/ FT, SL, PC, PS	1,2,3,5,7,8,11,12,15,16,18,20,21,24,25, 27,29,30,32,34,35,36,39,40,41	25
12	All	All 41 Members	41

2. NLW Maximum Effective Range

Varying the maximum effective range of the NLW will provide insight as to whether having increased range provides additional utility to the weapon system. Currently, the ERMM has a maximum effective range of up to 50 meters. The ERMM is already being used by the DOD, however, studying the importance of the maximum effective range will provide JNLWD with immediate insights into future procurement of like ammunitions. For this thesis 50% was added to the current maximum effective range. Additionally, the minimum value for maximum effective range is 30 meters. Like gaining insights about the utility of having a weapon system which is effective at further ranges, perhaps we may learn that the effective range does not have to be 50 meters to achieve the same results.

3. Number of Civilians

Allowing for variation in the number of civilians (both red and blue friendly) within the simulation allows for the exploration of different TTPs depending on the population density of the area the force is being deployed to. Generally, U.S. Embassies are located in population centers, however the insertion plan may not transit densely populated areas. Allowing the number of civilians in the simulation to vary from 20 to 300 provides insight into how the population density effects the employment of NLWs.

B. DOE METHODOLOGY

To allow for a range of possible analyses with the data, we use a space-filling design. We use an efficient, space-filling design called the nearly orthogonal Latin hypercube (NOLH) that Cioppa and Lucas (2007) describe as "one in which the design points are scattered throughout the experimental region with minimal unsampled regions" (45). The NOLH design was used for two of the factors and was then crossed with the factor for the NLW cases. The "cross" ensures that every design point within the NOLH is simulated for each case.

C. THE FINAL DESIGN OF EXPERIMENT

Utilizing the NOLH design on the number of civilians and maximum effective range of the NLW results in 17 design points. These points are crossed with the 12 NLW cases, resulting in 204 design points. Each design point represents one initial simulation setting of the scenario. Forty replications were completed for each design point, resulting in 8,160 simulated missions to "harvest" the data required to conduct analysis. Figure 9 shows the pairwise plots of the design points. The cross between the NOLH and NLW cases clearly fills the experimental space.

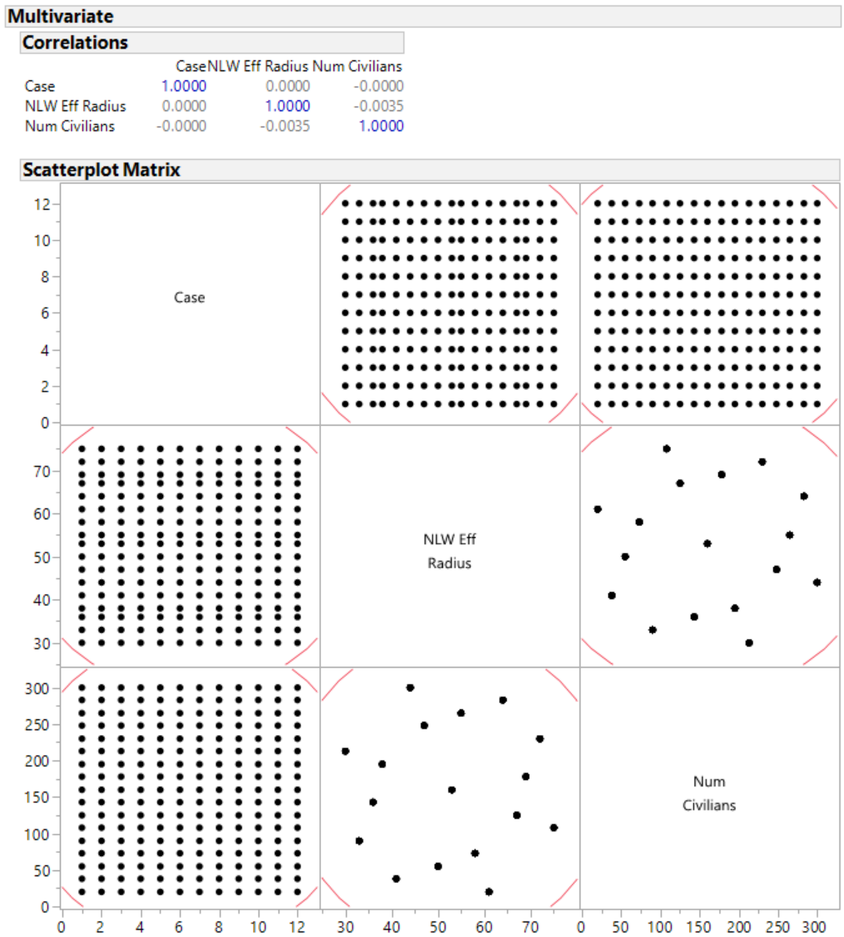

Figure 9. Correlation Matrix for Final Design

The pairwise correlation values in the table at the top of Figure 9 are nearly zero in all cases, showing that the factors within the simulation are nearly orthogonal, and thus are not confounded. Independence between the factors enables us to estimate regression terms that are independent. Random numbers allow us to treat replications as independent and identically distributed (IID). When conducting analysis, the assumptions associated with IID variables are extremely useful. The results show that these assumptions are valid.

D. TIME REQUIRED TO RUN THE EXPERIMENT

To compare the effectiveness of the NOLH design, I used the total time required to complete a single iteration of the simulation and the time required to complete all simulations. The simulation and factors for this research are simple, however one of the

factors plays a significant role in the runtime of each simulation. As the number of agents within the simulation increases, the time it takes to complete a single simulation experiment increases dramatically. The average duration for a simulation, using 125 civilian agents, on my Microsoft Surface Pro 3, was 34 minutes. But, through the Simulation Experiments and Efficient Design (SEED) Center at Naval Postgraduate School, running each simulation using the command-line version of Pythagoras (which is faster because it does not use the Graphical User Interface), the average simulation time for a single iteration could be reduced to around 10 minutes.

A full factorial design for this experiment, which involves running the simulation at every possible combination of inputs, would require 155,112 design points. To complete 40 replications at each design point would take over 401 years on my computer and 285 days using the SEED Center's cluster. Our final design with, 204 design points, at 40 replications for each design point, completed in just over 9 hours.

E. USING A VERIFICATION DESIGN OF EXPERIMENTS TO SET PARAMETERS IN THE MODEL

In Pythagoras, there are many values to be set which are hard to determine simply from an operational standpoint. Examples are ranges, firing rates, and accumulation of color or attributes associated with the voice or nonlethal weapons. Before we conducted the study we are interested in, described in the previous sections, we conducted a design of experiment over these values which were hard to determine, varying them over what we considered to be reasonable ranges. After conducting the simulations and setting the initial conditions the model was ready for face validation from multiple individuals with knowledge of NLWs, Pythagoras, and USMC patrols. Sargent (2007), defines face validation as "Asking individuals knowledgeable about the system whether the model and/or its behavior are reasonable" (128). The experiment results, along with the face-validation associated with running the simulation model with the selected values from the verification DOE, allowed us to verify and baseline our model.

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V. DATA ANALYSIS AND RESULTS

All models are wrong, some are useful.

—George Box
Professor of Statistics, University of Wisconsin, 1979

A. A "BOUNDING BOX" START

Prior to running the entire simulation across all design points, a "bounding box" of results was created to conduct a confirmation of the model's behavior and ensure it was behaving as intended. The bounding box was created by running 10 iterations of the simulation at the endpoints of each factor and varying them one by one over all combinations. The endpoint values for the number and location of the NLW were 2 and 41; where only the front and back Marine possess a NLW and everyone possesses a NLW, respectively. The endpoints for the maximum effective range were 30 meters and 75 meters. The endpoints for the number of civilians were 20 and 300. Table 6 depicts all of the endpoint values in a single location.

Table 6. Maximum and Minimum Factor Values

Factor	Minimum Value	Maximum Value
# NLW	2	41
# Civilians	20	300
ERMM Max Range	30	75

To confirm the model behaved as desired, I used personal experience and intuition. The expected results from the bounding box are outlined below:

- As the population density increases the number of lethal shots fired in the simulation should increase.
- The greater the effective range of the NLW the fewer lethal shots will be fired.
- Having more NLWs within the patrol will reduce the number of lethal shots fired.

Figure 10 shows the interaction profiler generated using JMP Pro 12. To best explain the interactions between the variables, the profiles in panels 3 and 6 will be used as a reference. The Y-axis is the average number of lethal shots fired during each simulation. This is also the response variable used in the full design. The X-axis in both panels is the number of civilians within the simulation. The two lines in panel 3 correspond to the NLW cases being used to create the bounding box. The blue line represents 2 NLWs within the patrol; one at the front and one at the back of the patrol. The red line represents all Marines within the patrol carrying a NLW. The lines in panel 6 represent the Maximum Effective Range of the NLW. The red line is 30 meters and the blue is 75 meters.

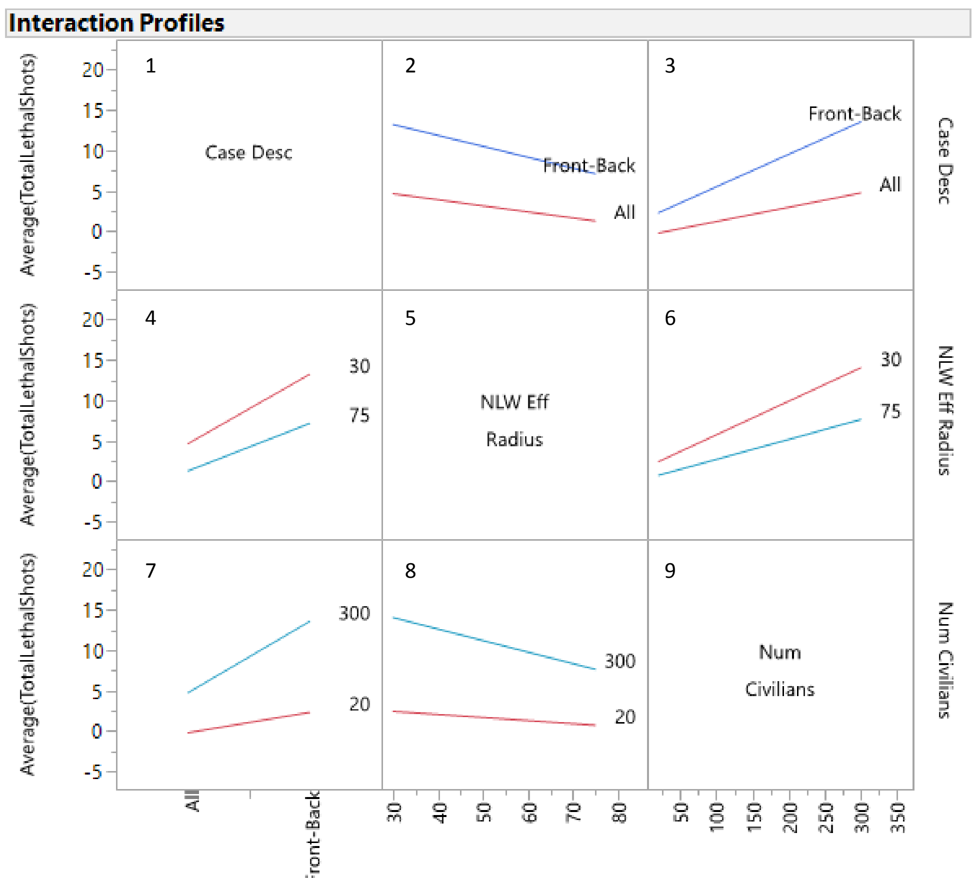


Figure 10. "Bounding Box" Interaction Profiles

The key takeaways resulting from creating the bounding box are below:

- Regardless of the number of NLWs within a patrol, as the population density increases so to do the number of lethal shots fired.
- Having more NLWs within a patrol reduces the number of lethal shots fired. The difference between lethal shots fired with 2 versus 41 NLWs grows as the population density increases.

The other plot in Figure 10 which is useful is panel 6. The X and Y axis remain the same as previously mentioned, however in this graphic the two lines represent the maximum effective range of the NLWs. Like changing the number of NLWs in the simulation, when changing the maximum effective range of the weapon system the number of lethal shots increases as the population density increases. However, when looking at the minimum and maximum values for the effective range there is a visible difference in the average number of lethal shots fired depending on the effective range. The further the weapon system can shoot; the fewer lethal shots fired.

After creating the bounding box and conducting some initial analysis of the results of the simulation it was clear that the model was behaving as anticipated. The initial analysis combined with watching multiple simulations to ensure the agent behavior resembled actions which would be performed in a real patrol gave face validation to the model. The validation and conclusions drawn from the bounding box experiment allowed us to progress to the full DOE described earlier.

B. FULL DESIGN RESULTS

The 8,160 experiments with the simulation produced an output comma separated value table consisting of 438 columns and 8,160 rows. Each column represented an output from a simulation run. The data farmed consisted of the number of shots fired for all weapon systems possessed, sidedness, number of kills, and final number of dead for all agents within the simulation. Additionally, the total number of lethal shots fired, total number of blue kills, number of red civilian kills, and number of red kills were also recorded for each simulation. This data was then compiled into 204 rows with the same number of columns. The compiled results would tabulate the average value for the 40

replications at each design point. For the following analysis, the average number of lethal shots fired was used as the response variable.

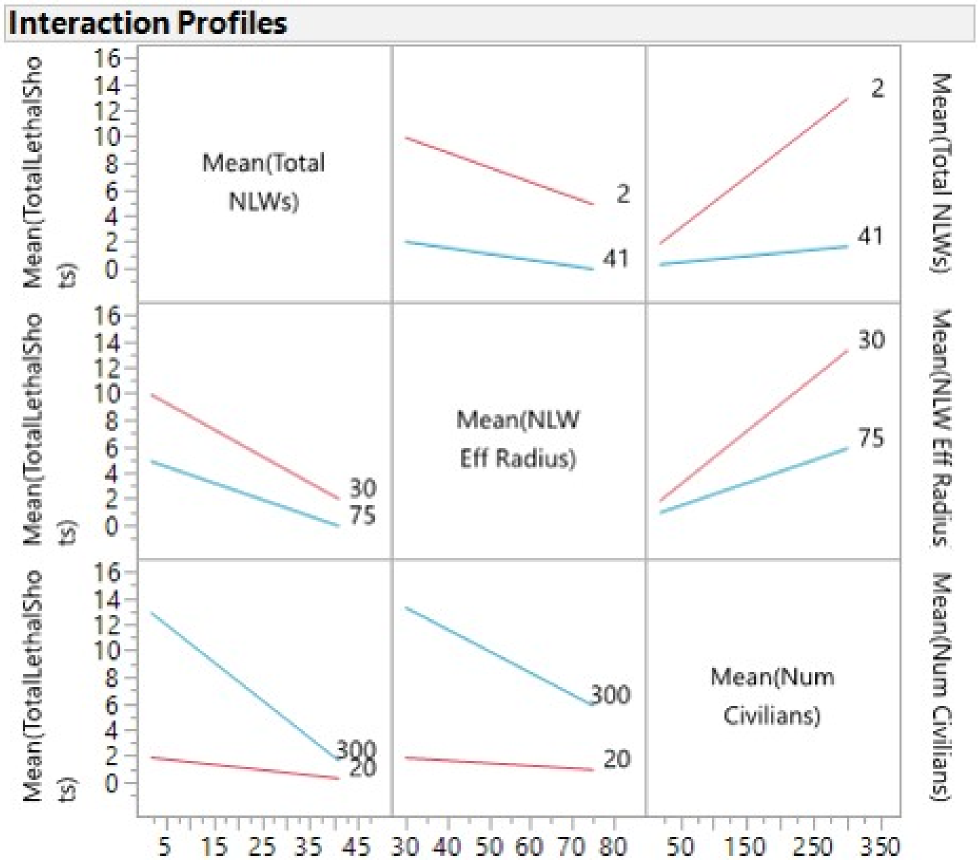


Figure 11. Full DOE Interaction Plot

Figure 11 depicts the same variable interactions used in the bounding box experiment using the data from the full set of simulation experiments. The results are very similar; however, it is interesting to note that the disparity between the high and low values is larger in the full simulation than it was when only the endpoints were used. Plotting the interaction profiles on the full data set served as a test to once again confirm that the model was behaving as expected. Further analysis was conducted as the full design results above made sense.

C. NLW IN DIFFERENT POPULATION DENSITIES

Population density is a common metric to determine how many civilians live within a region. The intent of varying the number of civilians within the simulation was to determine if NLWs are just as effective regardless of population density. For this, research population density was broken down into low, medium, and high. Table 7 shows the range of population density for each category. The following analysis explores how population density categories effect the employment of NLWs.

Table 7. Population Density Categories

Category	**Low Population Density (Persons / KM^2)**	**High Population Density (Persons / KM^2)**
Low	12	61
Medium	62	123
High	124	185

Due to limitations within Pythagoras, creating a population density which resembles a major metropolitan area is extremely difficult. For example, the population density of San Francisco is approximately 6,659 persons per square kilometer (Wikipedia 2017). To replicate this population density the simulation would require almost 10,800 civilian agents, which is beyond the reasonable capacity of Pythagoras. The maximum population density represented in this scenario is most closely resembled by the 2010 population density of Palm Springs, CA; which had a population density of 473.4 persons per square mile (United States Census Bureau 2010). This is approximately 183 persons per square kilometer. The areas of interest for this portion was the influence of the effective range of the NLW and the number and location of the NLWs within the patrol given a population density.

1. Number and Location of NLW in Different Population Densities

Figure 12 shows the results of the simulations broken down by population density and the different cases of NLW developed. The trend line added allows the reader to easily see where the most significant decreases in lethal shots fired are present. Standard errors for each mean were also calculated and added to the respective points.

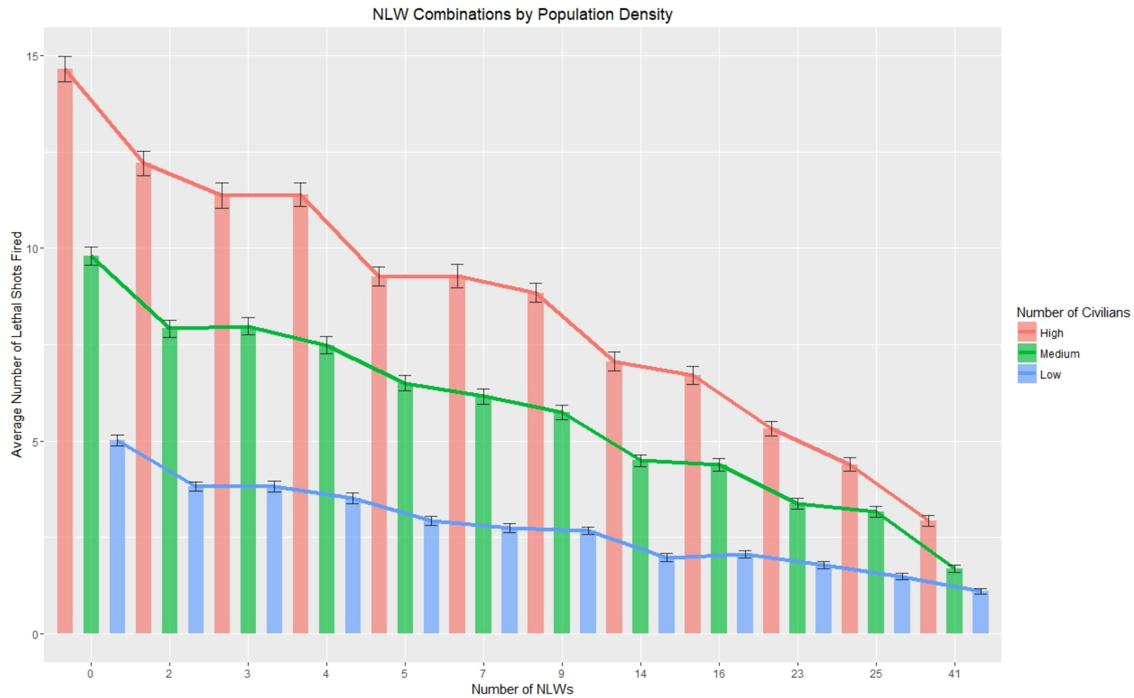


Figure 12. NLW Effects Based on Number of NLW and Population Density Category

Regardless of population density, there is a downward trend in the average number of lethal shots fired as the number of NLWs increase. Although the downward trend is positive, the percent reduction is vastly larger in high-density areas as opposed to the low-density areas. The number of interactions within a simulation is more frequent as the number of agents increases. With the low-density areas, the interaction frequencies are less, which reduces the potential for the scenario to become lethal. Table 8 shows the percent reduction in average lethal shots fired as the number of NLWs in the scenario increase. The reduction percentage is based on the number of lethal shots fired with the baseline being from the simulation with zero NLWs in the scenario.

Table 8. Percent Reduction in Average Lethal Shots Fired

	Number of NLWs											
Density	0	2	3	4	5	7	9	14	16	23	25	41
High	0%	17%	22%	22%	37%	37%	40%	52%	54%	56%	64%	76%
Medium	0%	19%	19%	24%	34%	37%	41%	54%	55%	57%	60%	79%
Low	0%	24%	24%	30%	42%	45%	47%	61%	59%	54%	61%	71%

Table 9 examines the results of the high population density experiments more closely. As seen in the graphic there is a continual downward trend in the average number of lethal shots fired as the number of NLWs increase. Additionally, the standard deviations and standard errors follow a similar downward trend. As more NLWs are added to the patrol there is less variation in the average number of lethal shots fired. This result makes sense from a tactical standpoint because as you increase the number of NLWs in the patrol you increase the area covered by NLW and the patrols area of influence. This extended coverage allows the agents to use NLWs to deescalate situations vice switching to lethal weapons.

Table 9. Summary Statistics of NLW Effects Based on Number of NLW in High Population Density

Total NLWs	Number of Civilians	Average Lethal Shots Fired	Standard Deviation	Standard Error
0	High	14.65	5.25	0.34
2	High	12.20	5.03	0.32
3	High	11.37	5.00	0.32
4	High	11.39	4.60	0.30
5	High	9.26	3.88	0.25
7	High	9.28	4.65	0.30
9	High	8.84	3.83	0.25
14	High	7.06	3.74	0.24
16	High	6.70	3.61	0.23
23	High	5.32	2.95	0.19
25	High	4.39	2.69	0.17
41	High	2.93	2.23	0.14

There are three significant points where the percentage of lethal shots fired are significantly reduced. The three cases were with 5, 14, and 41 NLW in the patrol. These three cases have the most significant impact on reducing the number of lethal shots fired in the simulation. Table 10 shows the reduction in the average number of lethal shots fired from the three cases selected above. The values depicted are the difference between the average lethal shots fired with zero NLW in the simulation and the average lethal shots fired with either five, 14, or 41 NLW in the simulation.

Table 10. Reduction in Average Lethal Shots Fired

Density	5 NLW	14 NLW	41 NLW
High	5.39	7.59	11.72
Medium	3.29	5.3	8.11
Low	2.08	3.04	3.9

The impact of NLWs in a high-density area is immediately seen when looking at the results of adding five NLW. The average number of lethal shots fired with five NLW in the scenario is 9.26, with a standard error of 0.25. This is a reduction in average lethal shots fired of 5.39, which is a larger reduction than adding 41 NLWs to a low-density patrol. When five NLWs are added to the patrol the squad leaders, platoon sergeant, and platoon commander are equipped with the NLW. By adding one NLW to each fire team, resulting in 14 total NLWs in the patrol the average number of lethal shots fired is reduced to 7.06, with a standard error of 0.24.

2. NLW Effective Range in Different Population Densities

After exploring the best weapons configurations in different population densities, we looked at the maximum effective range of the M1116 in different population densities. In an urban environment, the population density has an impact because of the proximity to personnel increases as buildings limit the movement of individuals and provide the perception that you are “blocked in.” The primary question being explored with this analysis is to see if having a larger effective range plays a role in an urban environment where buildings limit an individual’s line-of-sight.

Figure 13. NLW Effects Based on Maximum Effective Range and Population Density

Figure 13 displays the effects of the maximum effective range within the different population densities. The maximum effective range is divided into four categories: 30–50 meters, 50–60 meters, 60–70 meters, and 70–75 meters. Like the number and location of the NLWs within the patrol, there is a downward trend in the average number of lethal shots fired, as the maximum range of the NLW increases regardless of population density. The first category for effective range consists of the current capabilities of the M1116. The three latter categories are an exploration of the advantage from adding to the current maximum effective range of the munition. It is evident that an additional 10 meters in effective range provides a distinct advantage over the current capabilities in all three population densities. However, in a high population density it appears that when the effective range is between 60 to 70 meters the advantage gained is relatively minor compared to the advantage provided in the first 10-meters added to the current capability (50 meters to 60 meters).

Table 11 depicts the average number of lethal shots fired, standard deviation, and standard error for the high population density depicted in Figure 13. Like the statistics produced when exploring the number of NLWs to have in a patrol, as the maximum effective range of the NLW is increased the average number of lethal shots fired and associated variance also decrease.

Table 11. Summary Statistics of NLW Effects Based on Maximum Effective Range in High Population Density

NLW Effective Range	Number of Civilians	Average Lethal Shots Fired	Standard Deviation	Standard Error
30-50	High	10.22	4.69	0.12
50-60	High	8.68	4.10	0.19
60-70	High	8.03	3.57	0.16
70-75	High	4.32	2.02	0.09

Table 12 shows the reductions in the average number of lethal shots fired across the categories of the maximum effective range. The standard errors associated with the average number of lethal shots fired in the high population density, for each incremental increase in maximum effective range, are 0.19, 0.16, and 0.09 respectively. The small standard errors are an indication that the estimates of the mean are accurate, although there is variation in the average number of shots fired during any particular simulated mission. For example, the standard deviation for the average number of lethal shots fired in a high population density and a maximum effective range of 70–75 meters is 2.02. The reductions produced by increasing the maximum effective range of the NLW coincide with tactical intuition. In an operational environment if I have a weapon system with longer range I can engage potential targets from further away and more often. With a NLW the ability to reach further allows more time to react and deescalate situations which could otherwise lead to firing lethal shots.

Table 12. Reduction in Average Lethal Shots Fired by Population Density

	NLW Effective Range (Meters)		
Density	50-60	60-70	70-75
High	1.54	2.2	5.9
Medium	1.25	3.26	5.79
Low	0.55	2.33	3.43

These values shown are improvements from the current maximum effective range of 50 meters. The advantage of having an effective range greater than 50 meters is visible in Table 13, which shows the reduction of the average number of lethal shots as a percentage of the current baseline.

Table 13. Reduction Percentage of Average Lethal Shots Fired by Population Density

	NLW Effective Range (Meters)		
Density	50-60	60-70	70-75
High	15%	21%	58%
Medium	16%	41%	73%
Low	16%	68%	99%

The disparity in reduction percentage between the different densities in the 60–70 meter range is interesting and generated another focus area for the study. In the medium and low density simulation, there was at least an additional 25% reduction in the average number of lethal shots fired in the middle category. The 5% reduction in the high-density situations appears to be an anomaly but requires further exploration of the effective range in the high-density situations. The utility of the effective range is explored later in this chapter to determine the effects of the range given the scenario.

D. REGRESSION ANALYSIS

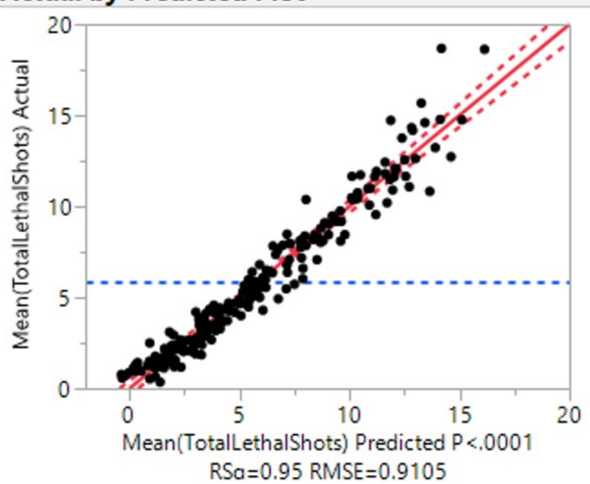
After our initial exploration of the results, regression analysis was conducted to confirm the earlier findings and ensure that the factors explored were statistically significant. Figure 14 shows the results of a stepwise regression for all factors, two-way

interactions, and second degree polynomials. The R^2 produced by the model is .95. This means that 95% of the variation in the model is accounted for by the factors used.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.4157292	0.321441	29.29	<.0001*
Total NLWs	-0.249573	0.007994	-31.22	<.0001*
NLW Eff Radius	-0.094703	0.004632	-20.45	<.0001*
Num Civilians	0.0309438	0.000744	41.62	<.0001*
(Total NLWs-12.4167)*(NLW Eff Radius-52.5294)	0.0016682	0.000399	4.19	<.0001*
(Total NLWs-12.4167)*(Num Civilians-160.235)	-0.000964	0.000064	-15.07	<.0001*
(NLW Eff Radius-52.5294)*(Num Civilians-160.235)	-0.000527	6.879e-5	-7.66	<.0001*
(Total NLWs-12.4167)*(Total NLWs-12.4167)	0.0050519	0.000438	11.52	<.0001*
(NLW Eff Radius-52.5294)*(NLW Eff Radius-52.5294)	-0.00308	0.000436	-7.06	<.0001*
(Num Civilians-160.235)*(Num Civilians-160.235)	-7.286e-5	1.116e-5	-6.53	<.0001*

Actual by Predicted Plot



Summary of Fit

RSquare	0.950946
RSquare Adj	0.94867
Root Mean Square Error	0.910488
Mean of Response	5.866054
Observations (or Sum Wgts)	204

Figure 14. Stepwise Regression Results

The extremely low *p-values* show that all the factors within the model, their two-way interactions, and polynomials to degree two are significant. The estimates for the coefficients also confirm the results previously discussed:

1. Adding NLWs to the scenario decreases the average number of lethal shots fired.

2. Increasing the maximum effective range of the NLW decreases the average number of lethal shots fired.

3. Increasing the civilian population increases the average number of lethal shots fired.

E. PARTITION TREE

A partition tree was created to explore the key factors within the study and to "tell a story" about which factors play an important role. Moreover, a partition tree suggests natural breaks within the data. The partition tree was created using JMP Pro 12 with five splits and is displayed in Figure 15. JMP uses recursive partitions of the data, developing relationships between the "X's" and "Y's" searching through all possible combinations to find the optimal splits. The R^2 for this tree is .76. This means that 76 percent of the variance is accounted for after five splits of the data.

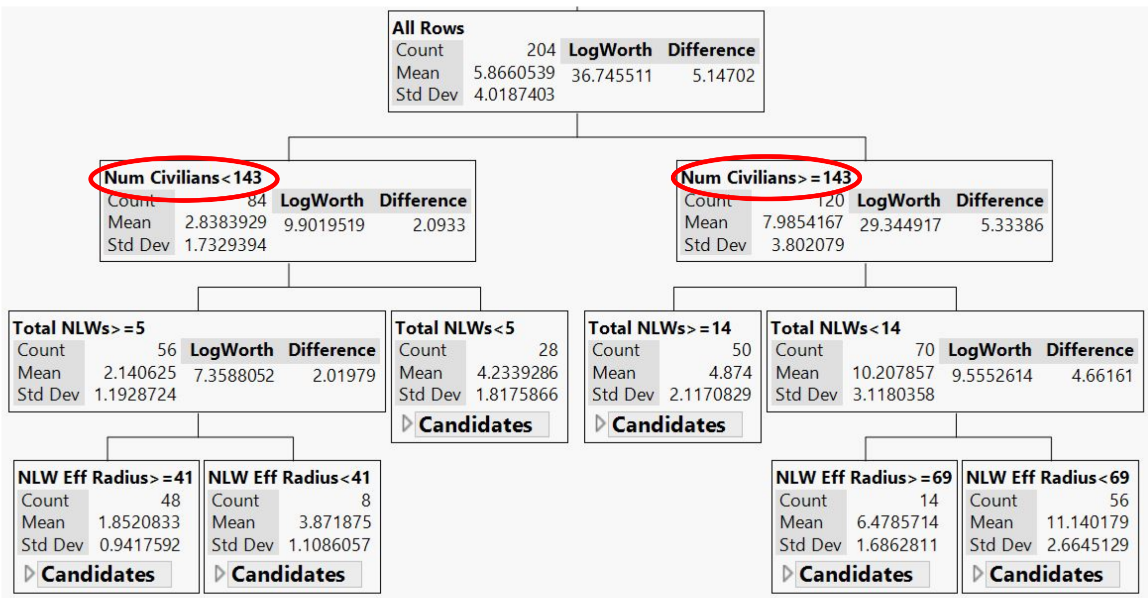


Figure 15. Partition Tree with Five Splits

The first split in the partition tree is generated on the number of civilians within the simulation. The split is nearly at the halfway point for the range of possible civilians within the simulation, and is highlighted in Figure 15. The results produced from the partition tree tell two unique stories which are explained below.

1. Civilian Population Less Than 143

The first branch created after splitting the data once consists of looking at the lower half of the population density. This means exploring what is important when the

patrol is operating in an area with at most a medium population density. Figure 16 shows this specific branch of the partition tree.

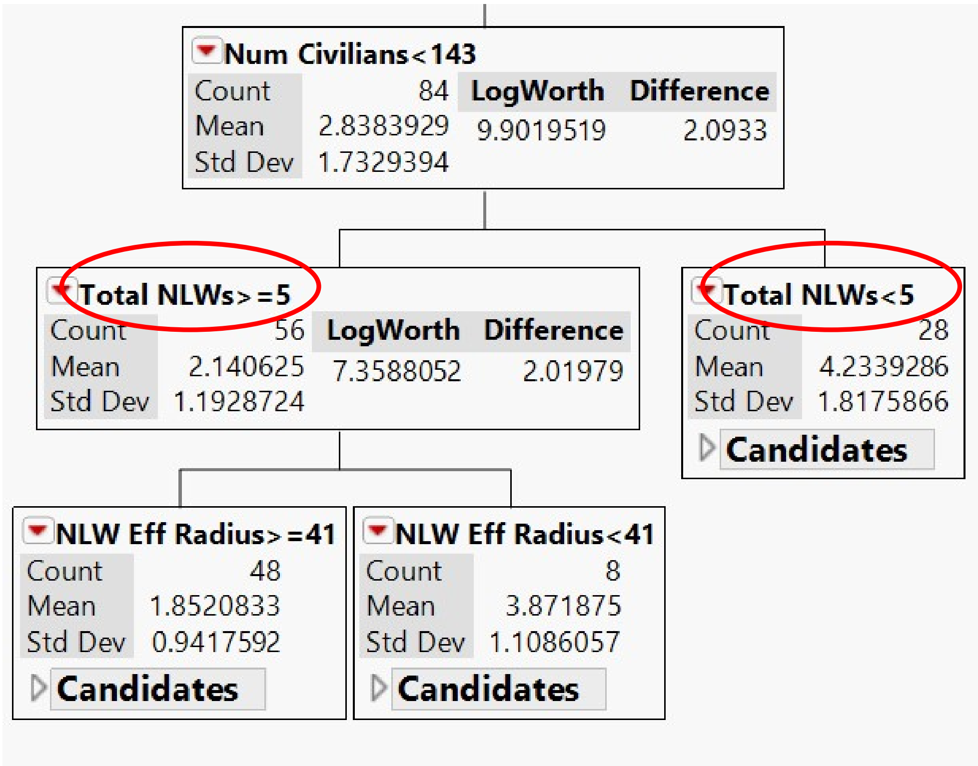


Figure 16. Partition Tree with Civilian Population Less Than 143

For population density to fall within this portion of the tree there is less than 89 persons per square kilometer on the streets. This is a low density and means that the patrol is operating in a rural area. Within this framework, the next most important factor is having five or more NLWs within the patrol. Having five or more NLWs within the patrol results in an average of 2.14 lethal shots fired, whereas having less than five NLWs results in an average of 4.23 lethal shots being fired. This finding indicates that it advantageous to have at least five NLWs within the patrol, even in an environment with a low population density. Tactically speaking this means that at a minimum each squad, the platoon sergeant, and platoon commander should carry NLWs when conducting a dismounted patrol. Having a NLW at the squad level in a lower population density confirms the intuition that if there is less potential for interaction with the local

population you will not need as many NLWs within the patrol. However, these results still show that NLWs are useful in reducing the average number of lethal shots fired, even in low population density areas. These results coincide with the earlier results, showing a significant drop in lethal shots when five NLWs are in the patrol. The final split on this branch of the tree involves having a maximum effective range of at least 41 meters. This is less than the current effective range of the M1116 and produces a result which provides little insight into the utility of effective range in this population density.

2. Civilian Population At Least 143

This branch of the partition tree provides some unique insights into the questions being asked in this research. The portion of the tree being explored is displayed in Figure 17.

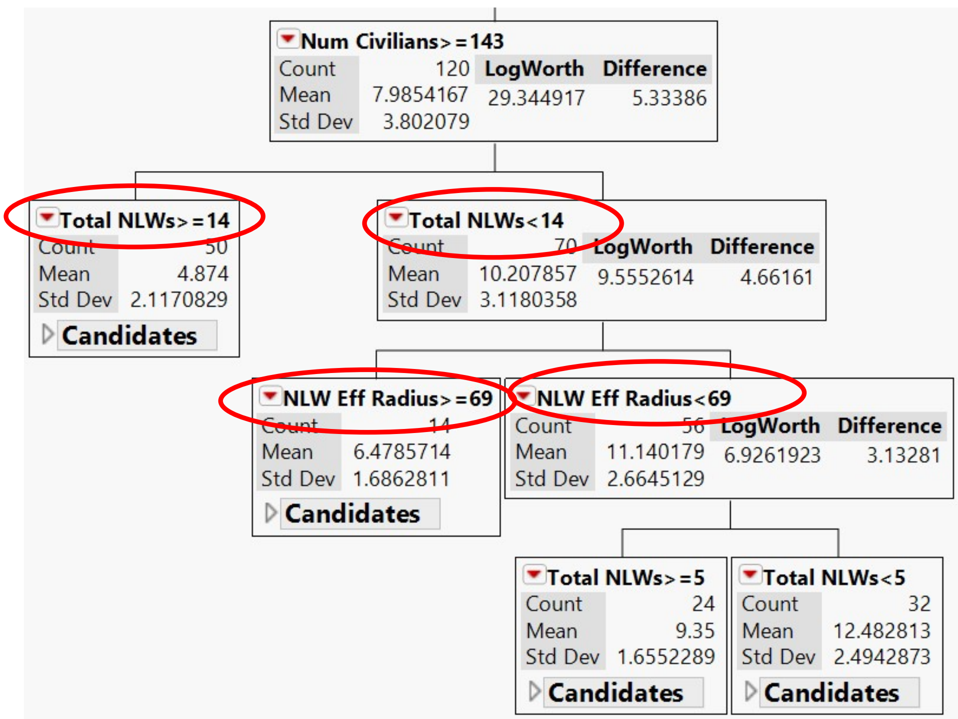


Figure 17. Partition Tree with Civilian Population Greater Than 143

The population density for this portion of the partition tree is greater than 88 persons per square kilometer on the streets. The first partition on this branch is at 14

NLWs within the patrol. When there are 14 or more NLWs within the patrol the average number of lethal shots fired is 4.87. Fourteen NLWs in the patrol means putting a NLW at the lowest tactical unit used in the USMC. Given that the patrol is operating in a highly-populated area, the probability of interaction with the local population is high, and having a NLW at the lowest tactical unit provides flexibility to the unit and its leadership. When there are less than 14 NLWs in the patrol there are over two times as many (10.2) lethal shots fired. This specific breakdown also coincides with previously identified key NLW cases being looked at. Another split on this half of the tree occurs when there are less than 14 NLWs within the patrol. The break occurs when the maximum effective range of the NLW is less than 69 meters. What this depicts is that if there are less than 14 NLW within the patrol in this given population density having a weapon system with a maximum effective range of at least 69 meters is the next most important capability. These results again coincide with what has already been discussed. These results confirm the utility to either having at least 14 NLWs within the platoon or having a greater effective range on the weapon system. Additionally, these results provide quantitative support to key findings and recommendations of this research.

F. EFFECTIVE RANGE IN A FOCUSED SIMULATION

The results previously discussed have shed light on the utility of improving the maximum effective range of the M1116. To further explore this area simulations were conducted where all parameters were held constant except for the effective range. Two of the key factors which were held constant for these simulations were the NLW case and number of civilians within the simulation. Case 8 was used for the NLW, where 14 NLWs were in the patrol. The scenario also used the maximum civilian population tested, which was 300. These values were chosen based on the results already discussed where in a high-density scenario 14 NLWs provided the “most bang for the buck.” The maximum effective range of the M1116 was varied from 30 meters to 100 meters by five meter increments. Each increment of the effective range was treated as a design point and 100 simulations were conducted at each design point. The results were compiled in JMP Pro 12 and R was used to create Figure 18, showing the decline in the average number of lethal shots fired as the maximum effective range of the NLW was increased. A Loess

smoother was used on the data to create a continuous vice discrete depiction of the reduction in lethal shots fired. Lyn Whitaker gave a lecture in July 2016 titled "Smoothers" where she described a Loess smoother as a method to "fit a weighted regression (usually quadratic) to (x,y) whose x are in the 'neighborhood' of x_o." The bold red line represents the "smoothed" average number of lethal shots fired, while the red shaded area is one standard error.

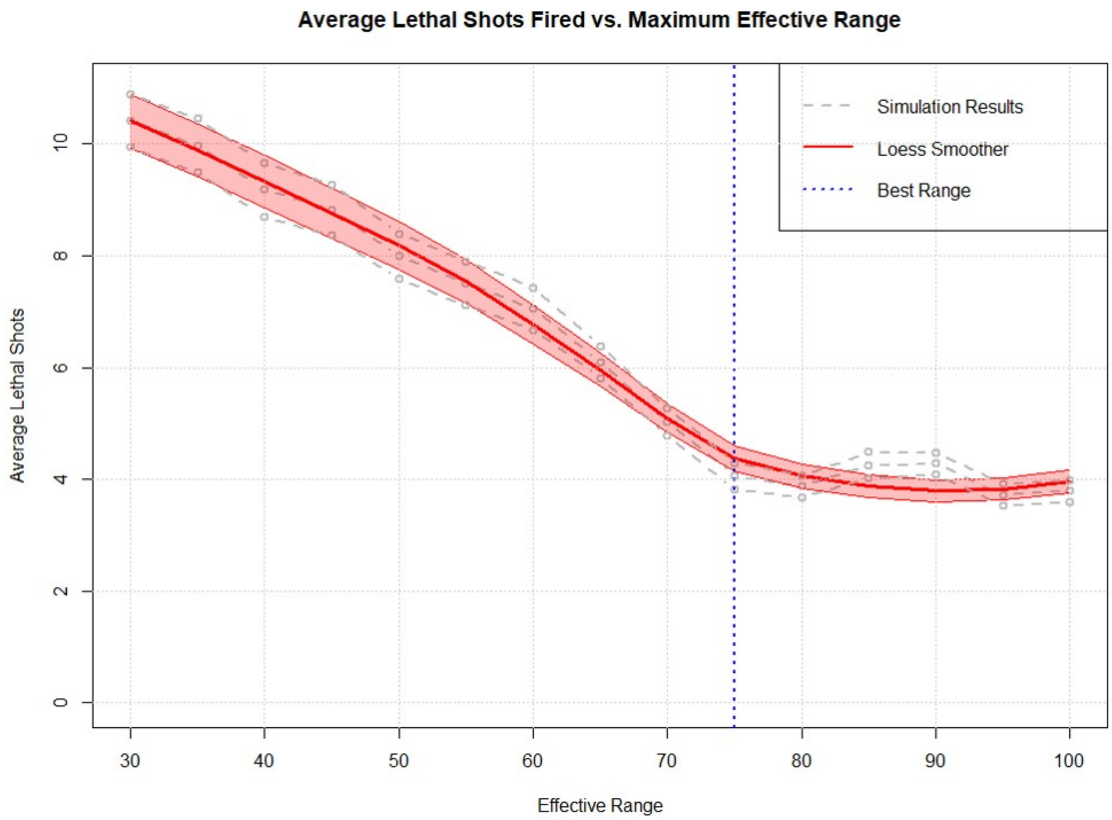


Figure 18. Results of Varying Effective Range in
Focused Environment with Standard Error

The results of the simulations show a general downward trend with the occasional increase in average number of lethal shots. These slight increases are never larger than .5 shots and are a result of the stochastic nature of the simulations. As previously mentioned, a Loess smoother was added to the graphic to show an estimation of the general downward trend given the results of the simulation. The values of interest occur

at 50 meters, which is the current maximum effective range, and 75 meters, which can be labeled as the “knee in the curve.” At 50 meters the average number of lethal shots fired in the simulation was 7.2. By increasing the maximum effective range to 75 meters the average number of lethal shots fired is reduced to 4.0. This is a 45% decrease in the average number of lethal shots fired.

The same data was used to create Figure 19; however, the standard deviation is depicted vice the standard error. This graphic shows the variability within the experiments, however, the downward trend and “knee in the curve” are still present and confirm the conclusions drawn from Figure 18.

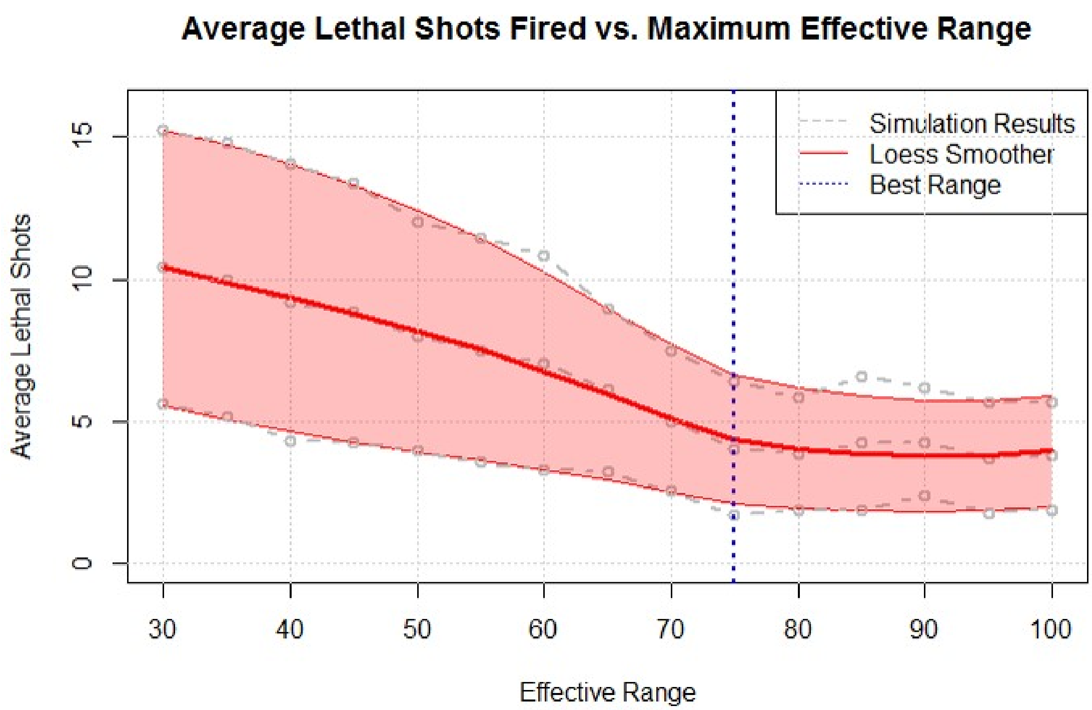


Figure 19. Results of Varying Effective Range in Focused Environment with Standard Deviation

VI. CONCLUSIONS AND FUTURE RESEARCH

> Our experience in Somalia with non-lethal weapons offered ample testimony to the tremendous flexibility they offer to warriors on the field of battle.
>
> —Lieutenant General Anthony Zinni, USMC
> Somalia Task Force Commander 1995
> (Quoted in Levine 2015, 243)

A. DISCLAIMER

This research has strived to simulate a Marine patrol in a semi-permissive environment. Simulating reality is hard and many assumptions were made so the agents within the model resembled the "real-world" as closely as possible. Multiple simulations were observed to verify that the agent's behavior reasonably resembled that of human behavior as close as possible based on expert judgements. This assessment was completed by multiple individuals and helped guide the development of the model. The results and conclusions drawn from the simulations are for a very specific set of parameters, however they are clear and provide insights into questions being asked by the JNLWD.

B. NLW EMPLOYMENT

The fundamental question being asked in support of this research was to answer "how many and where" should NLWs be utilized if a SPMAGTF-CR is tasked to complete an embassy reinforcement. No two embassy reinforcement missions will be the same, as location, population atmospherics, weather, and unit capabilities will always vary. However, the TTPs practiced by those USMC units training for this specific mission are equivalent across the service. The results of this study can serve as a baseline from which to estimate from when conducting initial planning for a mission. The results and analysis discussed in the previous chapters show that in a semi-permissive environment 41 NLWs would result in the lowest number of average shots fired given the scenario. This is somewhat intuitive, however, from a tactical standpoint is simply not feasible. From the author's personal experience, the recommended number of NLW

systems to have in a patrol is 14. This number produces a greater than 50% decrease in the average number of lethal shots being fired, in all three population densities, while still being tactically sound. Having 14 NLWs within a platoon follows USMC doctrine for the employment of certain weapon systems such as the automatic rifle. Furthermore, the recommended location of the NLWs within the reinforcement patrol is broken down below:

- 1 NLW per Fire Team
- 1 NLW per Squad Leader
- Platoon Commander
- Platoon Sergeant

From a tactical perspective, this breakdown of NLWs within a platoon provides the leadership with tactical flexibility. Marine Corps doctrine involves pushing decision making ability to the lowest level possible. Ensuring each fire team can employ a NLW ensures the leadership within the platoon can focus on other aspects of their mission vice focusing on the inward actions of their unit. For a lower density or less threatening situation, only five NLWs may be required.

C. EFFECTIVE RANGE

The decision to specifically study the utility in changing the maximum effective range of the M1116 evolved from a meeting with JNLWD in which the author was conducting an in-progress review of the research. JNLWD is continually working to improve the NLW capabilities within the DOD and during the meeting the directorate stated that it was in the process of identifying initial requirements in the procurement of a new munition like the M1116. An area which is critical to the procurement of a new blunt force munition is the desired maximum effective range. The research conducted on the utility of increasing the maximum effective range of the munition provides the JNLWD quantifiable insights and perspective on the positive impacts of increasing the range when establishing the initial capabilities of the new munition. The results of the research show the most ideal maximum effective range of the blunt force munition is 75 meters. The 45% reduction in the average number of lethal shots fired provides quantifiable

information for the directorate. Providing JNLWD with quantifiable values gives the directorate with supporting documentation when identifying requirements. Additionally, the smoothers added to Figures 17 and 18, provide estimates of the average number of lethal shots fired. These reductions provide initial estimates on the advantages provided by incrementally increasing the maximum range. There may be significant costs and other contributing factors which will determine how JNLWD establishes the initial maximum range capabilities. However, these results will aide in making a quantitative decision.

D. FUTURE RESEARCH

There are many areas for future exploration regarding the model, weapon system, or situation/atmospherics of the agents within the model. This section briefly outlines potential areas for follow-on research broken down by the three categories previously mentioned.

1. Model Improvements

Many assumptions were made while developing the model to ensure the agent behavior closely resembled that of human behavior. Making the model three dimensional would provide insights into how narrow alleys or tall buildings effect a unit’s ability to properly employ NLWs in an urban environment. Another area for improvement would be to employ the Marine patrol in different tactical formations. The “Ranger File” was employed in this model. However, there are many other methodologies and TTPs for conducting dismounted urban patrols. By modeling different TTPs, one may find a change in the number of weapon systems required or a different optimal maximum effective range.

2. Weapon System

The ERMM is an excellent weapon system to model because its employment is similar to conventional weapon systems with different effects. An area which was not explored is the minimum safe distance of the weapon system. This minimum safe distance is extremely important as the propensity to cause significant damage or death

increases if it is fired within the minimum range. The ERMM has a minimum range of 10 meters. Using simulation and treating the minimum range of the weapon system as a factor would provide JNLWD with insights into whether there is benefit in decreasing or increasing this range.

As previously mentioned, there are many NLW systems employed by the DOD. Modeling the utility of other weapon systems within a dismounted patrol would provide leaders with different options when conducting an embassy reinforcement mission. By properly modeling another NLW you can compare the weapon systems or mix and match them to see what the best mixture of lethal and non-lethal weapons truly is.

3. Scenario

There are multiple options for changing the scenario which would help shed light on the best TTPs for employing the ERMM or a different NLW. Some suggestions are below.

- Increase the population density to the capacity of Pythagoras. As agents are added to the simulation the time for one iteration of the simulation increases. With enough time one could increase the population density to resemble that of a major metropolitan area.
- Change the ratio of blue and red friendly civilians within the scenario to determine if there a point in which NLW no longer have an effect.
- Generate more red agents within the scenario.
- Model the human effects of NLWs. The effect of the ERMM was determined based on conversations with JNLWD with minimal analytical rigor. Work is currently being done to mathematically model a distribution of how NLWs effect people, as no two people respond in the same way to a NLW. Incorporating the results of the study to model agent behavior to the model would further validates its utility.
- Formally explore many other inputs to the simulation (e.g., the influence of the voice weapons, the number of Red Forces in the scenario, etc.)
- Explore other ABS environments to explore the same factors.

E. CONCLUDING REMARKS

The "New Normal" operating environment does not appear to be changing anytime soon. The DOD will continue to be called upon to fight our nation's battles and must be prepared to operate in densely populated areas where the local populace is both with us and against us. The utility of NLWs in these environments cannot be overstated. The DOD requires the capability to incapacitate, but not kill, potential adversaries and minimize potential civilian casualties. As long as there are U.S. diplomats in foreign countries the DOD will maintain the mission of being able to secure our citizens. NLWs serve as a force multiplier in these situations and potentially reduce the number of civilian casualties. Continuing research into NLW TTPs and employment will support those members of the DOD who support U.S. citizens and diplomats abroad.

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APPENDIX. MODEL ASSUMPTIONS

- Communication between agents of the same class is always working. All agents of the same class become "aware" of what those in the same class are aware of.

- Red Force's probability of hit and probability of kill are 1.0 (perfect) when firing the AK47 weapon system at Blue Forces.

- Dimensionality. The model operates in two-dimensional space.

- Buildings on the game board are unable to be entered by agents.

- The effects of the ERMM is 30 time steps. Agents struck by the NLW lose the ability to move and communicate for the duration (30 seconds).

- Human factors and response are assumed to be uniformly distributed with various means and standard deviations. (i.e., response to Blue Force voice ranges from adding 10 red to adding 20 blue).

- If the scenario transitions to use of lethal weapons the Blue Force will no longer use NLWs.

- The civilian population is 2/3 blue friendly and 1/3 red friendly.

- There are no friendly fire incidents.

- Agents can only be engaged by one NLW system. If a member of the Blue Force engages a civilian with the NLW other members of the patrol will not engage the same agent with their NLW.

- The minimum safe distance for the NLW modeled was never changed.

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